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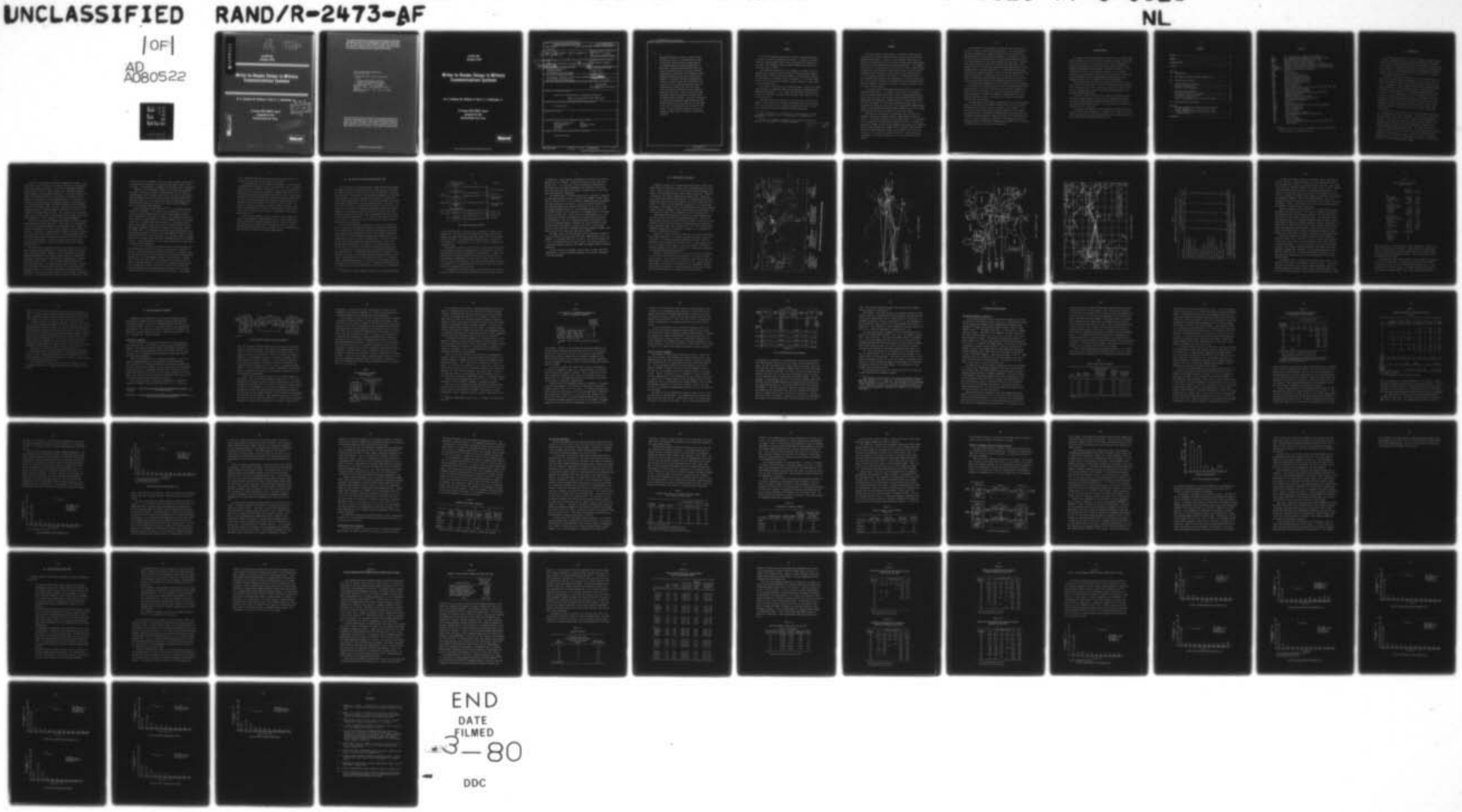

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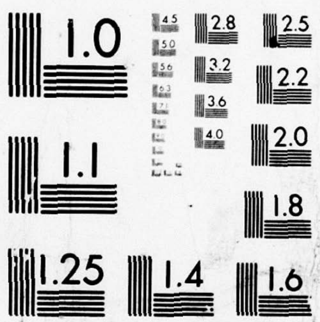

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Writer-to-Reader Delays in Military Communications Systems

N. E. Feldman, W. Sollfrey, S. Katz, S. J. Dudzinsky, Jr.

A Project AIR FORCE report
prepared for the
United States Air Force

Rand
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This report presents

Background material to place in proper context the effect of the use of millimeter-wave earth-to-satellite links on military communications. The complete writer-to-reader message path is described, including administrative delays (approval, awaiting pick-up, local mail delivery), communications processing, and transmission time. Analysis of statistics on speed of service for AUTODIN, the principal military communications network at present, shows that the smallest contributions to the total message delay come from communications transit time, the only system delay that would be affected by rain outages in millimeter wave links. Over 25 percent of high-precedence traffic is delayed by several hours in administrative handling. The delay distribution is severely skewed toward larger delays, and the AUTODIN network serves the majority of users much better than is indicated by the mean delay. The report is a basic building block to place rain outages on EHF links in a realistic perspective. (Authors)

PREFACE

This report examines message traffic delays and possible causes of delay in a military communications network. It seeks to provide a realistic baseline against which future requirements and designs can be judged. The AUTOmatic DIgital Network--AUTODIN--was selected as a convenient source of data.

The immediate application of this baseline, or datum, will be to evaluate rain outages for millimeter-wave earth-to-satellite communications links. Placing these rain outages in a statistically meaningful relationship to all other delays is essential.[*] "All other delays" refers to the entire writer-to-reader sequence; AUTODIN is only a part of that chain of events.

This report[†] is the first to be published under a Project AIR FORCE study entitled "An Analytical Basis for the Design of Usage-Compatible Communication Systems." It is a basic building block in placing rain outages for atmospheric Extremely High Frequency (EHF) links in a realistic perspective.

Additional statistical analysis in a later report--for which the present report provides the necessary background--will show the actual effect of rain outages on the complete delay distribution for a military communications system employing millimeter-wave links.

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[*] See *A New Approach to Millimeter-Wave Communications*, The Rand Corporation, R-1936-RC, by N. E. Feldman and S. J. Dudzinsky, Jr., April 1977.

[†] Nathaniel E. Feldman, originator of the project and one of the authors, is a consultant to The Rand Corporation.

SUMMARY

The basic purpose of this report is to place in proper context the effect of the use of millimeter-wave satellite links on military communications systems. Concern over rain outages has severely retarded the operational use of such links, although Lincoln Experimental Satellites 8 and 9 demonstrated successful development. The argument has been that the links must have 99.9 percent or better annual average availability, which requires the down links to have so much satellite transmitter power available to meet rarely occurring events that operation becomes economically unattractive. We have argued that for many communications purposes this requirement is unduly stringent, and that rain outages, which act as an additional source of message delay, should be compared to delays in existing or proposed systems to evaluate their effects properly.

This report provides background material necessary for such comparison and evaluation. It presents a description of the complete writer-to-reader message path, which includes outgoing administrative delays that occur while the message is being approved and delivered to communications headquarters, communications processing delays between the time the message is filed at the transmitting center until it is available for delivery at the out box of the destination communications center, and incoming administrative delays between the time the message arrives at the out box to its delivery to the final reader.

Following the description of the message path, we discuss the AUTODIN I system, the principal military communications network at present. The general description of the system leads to a presentation of its standards for reliability and speed of service. The Army Communications Command and the Defense Communications Agency have conducted studies (Army Communications Command Writer-to-Reader Study (ACCWRS) and Switch Network Analysis Profile System (SNAPS) that provide statistics for the various time delays noted above. We have obtained information on the delay characteristics of the network from these studies.

We found that the distribution of values for any of the time intervals is severely skewed toward larger delays. The distribution is not well represented by a normal distribution, nor do the mean and variance describe the distribution adequately. The majority of users are much better served than would be indicated by the mean, but there is a large population of long delay messages (the outliers). Improvements in the speed of service for these outliers would have a much greater payoff for the overall system than would improvements for those messages which are already handled well. The administrative delays, especially for incoming messages, are by far the most important contributors to long delays. Halving the time that messages spend in out boxes or local mail delivery would have much more effect on the total delay time than would halving the communications processing times.

The reliability standards are met satisfactorily by the redundancy in the network, but the presence of the outlier population makes the 95 percent points of the delay distribution, at which the standards for speed of service are defined, lie at very large delays which do not meet the standards. Either the standard is unrealistically low and simply cannot be achieved, or the causes of the outlier population must be found and corrected.

The data show that the smallest contributions to the total message delay are provided by the AUTODIN I transit time. This is the only portion of the total delay which is affected by rain outages. We assert that the rain-caused delays should be compared to the complete message path delay, technological (communications processing and transmission) and nontechnological (approval, pickup, and local mail delivery), if a proper context for evaluation of millimeter-wave earth-to-satellite links in AUTODIN-type communications systems is to be achieved. A forthcoming report will make this comparison.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of Dr. Robert Naka (Chief Scientist of the Air Force at the time), who helped to arrange for Air Force support of this project and who gave encouragement throughout the work; Maj. Gen. Timothy Ahern, former Assistant DCS/ Research, Development and Acquisition, the project sponsor; Lt. Col. Joseph Violette, the original project monitor; Lt. Col. Richard Crawford, the current project monitor in the Directorate of Space Systems and Command, Control & Communications; and Maj. Gen. Van C. Doubleday and Maj. Gen. Otis Moore for their encouragement.

The data used in this report were obtained with the help of Mr. Jerry King and Ms. Mary Minor of the U.S. Army Communications Command at Ft. Huachuca; Capt. Alan G. Nabb and Maj. Robert J. Nowell of the Air Force Communications Service; and Col. William Misencik of the Defense Communications Agency.

Support in a number of other areas related to millimeter waves and optical communications was received for complementary research from the Military Satellite Communications Systems Office (MSO) of the Defense Communications Agency. Dr. Pravin Jain of the MSO was the project monitor of that work.

Significant contributions to the background research associated with this report were provided by E. Sharkey and J. Ratkovic. We also wish to acknowledge the many helpful comments of the Rand reviewers of this report, Steven Glaseman and Cullen Crain.

CONTENTS

GLOSSARY*

ACC	Army Communications Command, Fort Huachuca
ACCWRS	Army Communications Command Writer-to-Reader Study
AMME	Automated Multi-Media Exchange (MPDS, OCR)
ARPA	Advanced Research Projects Agency
ASC	Automatic Switching Center (AUTODIN) ("Switch")
AUTODIN	Automatic Digital Network, narrative and data (AUTOVON)
AUTOSEVOCOM	Automatic Secure Voice Communications, on AUTOVON system
AUTOVON	Automatic Voice Network, telephone
BIT	Binary digit
BPS	Bits per second
CONUS	Continental United States
DCA	Defense Communications Agency
DCS	Defense Communications System
ECP	Emergency Command Precedence
EFTO	Encoded for Transmission Only
EOMI	End of Message In
EOMO	End of Message Out
HF	High Frequency; (ELF, VLF, LF, MF, HF, VHF, UHF, SHF, EHF)†
IST	Interswitch Trunk (AUTODIN)
LES	Lincoln Experimental Satellite
MPDS	Message Processing and Distribution System, USN
MT	Management Threshold
NCS	National Communications System
OCR	Optical Character Reader (AMME, MPDS)
O&M	Operations and Maintenance
RADAY	Radio Day
RP	Restoration Priority
SNAPS	Switch Network Automatic Profile System (AUTODIN)
SOMI	Start of Message In
SOMO	Start of Message Out
SOS	Speed of Service
TAD	Time Available for Delivery
TCC	Telecommunications Center, message center
TOF	Time of File
TOR	Time of Receipt
TOT	Time of Transmission
VHF	Very High Frequency; (ELF, VLF, LF, MF, HF, VHF, UHF, SHF, EHF)†

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*Related acronyms are listed in parentheses after the definition.

†Listed in order of ascending frequency.

I. INTRODUCTION

It has become clear that it will be necessary to expand military satellite communications systems into the millimeter-wave frequency region, which extends roughly from 20 GHz to 300 GHz. The Rand Corporation has been studying the theoretical and practical consequences of this expansion. A general discussion of the advantages and disadvantages of use of the millimeter-wave band appears in Ref. 1, and supporting analysis appears in Ref. 2.

Physical and electronic survivability can be enhanced, and interference and spectrum congestion alleviated, by the use of earth-to-satellite millimeter-wave links instead of the conventional microwave links. Nevertheless, concern about rain outages has rendered communicators reluctant to exploit millimeter waves. During periods of sufficiently intense rainfall, the attenuation produced by the rain may render the link inoperative. It has been argued that the mere existence of rain outages makes the use of the millimeter-wave band untenable or, more mildly stated but having equal effect, that every link must be required to have 99.9 percent or better annual average availability, which condition forces the down link to have so much satellite transmitter power available that it becomes economically unattractive.

We have advanced the viewpoint that for many communications needs these requirements are unduly stringent. A rain outage is equivalent to an equipment failure; both produce a delay in the transmission of messages. After the rain eases, the system can resume operation. We therefore argued that the additional system delay produced by rain outages should be compared to the delays which exist in present or currently planned communications systems. This comparison would provide a proper context for the rain effects, rather than comparing them to an arbitrary standard which may not be met at present. To make the comparison, it is necessary to obtain data on the types of delays that may occur in present communications systems.

There are several types of military communications systems. Certain links, such as the hot line to Moscow, require that instantaneous connections always be available. We would not recommend millimeter waves for such circuits. Other systems, such as AUTOVON (AUTOmatic VOice Network), are of telephonic character, in that the message originator is connected directly to the recipient. The delays in such systems are determined by line availability and by the presence or absence of the recipient at his AUTOVON connection. According to Ref. 1, a study conducted at SAMSO in 1975-1976 showed that their AUTOVON connection (33 outgoing lines) typically experienced several 10-minute blockages each day, and had blockages lasting three to four hours on as many as four days during the year. Thus, delays may be quite appreciable on these direct paths, and millimeter waves systems, which suffer short outages due to rain, should not be dismissed offhandedly.

There are other military communications systems for which the communications path is more complicated. These involve the transmission of written or recorded information, either narrative text or data. The message is generated by the source, must generally receive approval, and then is delivered to communications personnel who process and transmit the message to the recipient's base. It may then undergo further processing, await pickup, and finally be delivered via local mail service to the addressee(s). All these procedures may involve delay. Communications systems of this type carry the bulk of U.S. military message traffic.

We have selected a particular system of this last type, the AUTOmated DIgital Network (AUTODIN I), as our primary subject for investigation of message delays. AUTODIN I, which is managed by the Defense Communications Agency (DCA) through a Deputy Director of Operations (Code 500), constitutes the backbone for the transmission of military long-haul message traffic. It is currently operational and is not using millimeter waves. The entire message path from writer to reader can be characterized, and we have been able to secure suitable data on system delays. It is therefore appropriate to compare delays in AUTODIN I with delays which might result from rain outages on millimeter-wave links. This report does not consider whether millimeter-wave links

should be used in the AUTODIN system, but rather considers how to place in perspective the changes in system delay that might result if they were used. The employment of redundancy should reduce these consequences.

AUTODIN I will be gradually replaced by the higher speed AUTODIN II system. However, the impact on queueing delays of this change is unpredictable, since the higher speed service may attract more traffic. Although AUTODIN II will offer more rapid and reliable transmission of large data files, it is not expected to offer much improvement in narrative message handling, at least in the early years when AUTODIN I and II are operating simultaneously.

Several studies have been published[3-5] on the message handling capability of AUTODIN I. The first of these studies, Ref. 3, one in a series of Switch Network Analysis Profile System (SNAPS) reports, gives information on the speed of service of the communications portion of the writer-to-reader path for the entire AUTODIN system. The second study (Ref. 4, a general description, and Ref. 5, an analysis of the effect of precedence) reports on an exercise conducted by the Army Communications Command, Fort Huachuca, Arizona, and is generally called the ACCWRS study. This study collected data on both administrative and communications delays for traffic which used AUTODIN I during the period March 1975-March 1976. Both studies are very extensive (about 2,410,000 records for the SNAPS reports and about 1,660,000 records for the ACCWRS report). The data presented in these studies constitute our main sources of message delay information.

In Sec. II, we describe the complete writer-to-reader message path. The delays which occur on this path may be split into two general categories, processing delays and administrative delays. Processing delays are those which occur while the message is in the hands of communications personnel or is in electromagnetic transit between stations. Administrative delays are those which occur between the time the writer completes the message and when it is delivered to communications personnel at the transmitting station, and also those which occur between the time the message leaves the communications personnel at the receiving station and when it is delivered to the eventual reader. Rain outages

on the communications path would add to the processing delays, but would have no influence on the administrative delays.

To understand the data on AUTODIN I performance, it was necessary to understand the context in which it was collected. Thus, a layman's description of the network is presented in Sec. III, and a description and discussion of the system performance standards appear in Sec. IV. Following this descriptive material, we present in Sec. V a statistical analysis of the delay distributions, compare the measured delays with the speed of service standards, and discuss the large population of messages with very long delays--the "outliers." Most of Sec. V is devoted to analysis of messages of Flash or higher precedence level, since these should have the shortest expected delays, and therefore would be most affected by rain outages. Conclusions of the analysis appear in Sec. VI.

This report is primarily devoted to description and analysis of delays in the AUTODIN I communications system. A later report will provide additional statistical analysis and will show the effects of rain outages on the complete delay distribution, thereby providing suitable context and information to evaluate the use of millimeter-wave earth-to-satellite links for military communications.

II. THE COMPLETE WRITER-TO-READER MESSAGE PATH

The active life of a message includes passage through many handlers. The complete writer-to-reader path in Fig. 1 shows who has the message at various times in the process, with a set of definitions of times and time intervals. First, within the originating headquarters, the message writer composes the message, prepares an initial list of addressees, and has the message typed. The next step, message approval, may involve considerable coordination at several approval levels. From Fig. 1, the first time interval T_1, coordination and approval, begins with the completion by the writer of the draft message and ends with final message approval. The message then must move from the out box of the final approving officer to the in box of the Telecommunications Center (TCC) at the originating headquarters. This delivery time interval is shown on Fig. 1 as T_2. Together T_1 and T_2 constitute the outgoing message administrative handling time.

At the TCC, the message is marked with a time of file (TOF), retyped if necessary, and routing indicators are added for each address. It is converted into an electronic signal and forwarded via the tributary circuit of the originating TCC to the first Automatic Switching Center (ASC)* of the interstation communication system, where it is momentarily stored as it joins the message queue. The time of arrival at the first ASC may be measured either by the start or end of the message signal (SOMI/EOMI). The interval from first arrival at the TCC to arrival at the first ASC defines the outgoing processing time T_3. The message is then transmitted over the interstation network to the destination ASC. Several intermediate ASCs may be involved in the transmission process. The message travels on another tributary circuit from the destination ASC to the destination TCC, where it is acknowledged, a confirmation message is sent back to the originating ASC, and the message is reconverted to hard copy. The network transmission time, T_4, measures the interval from arrival at the first ASC to reconversion

*We apply this specific AUTODIN terminology to the general network.

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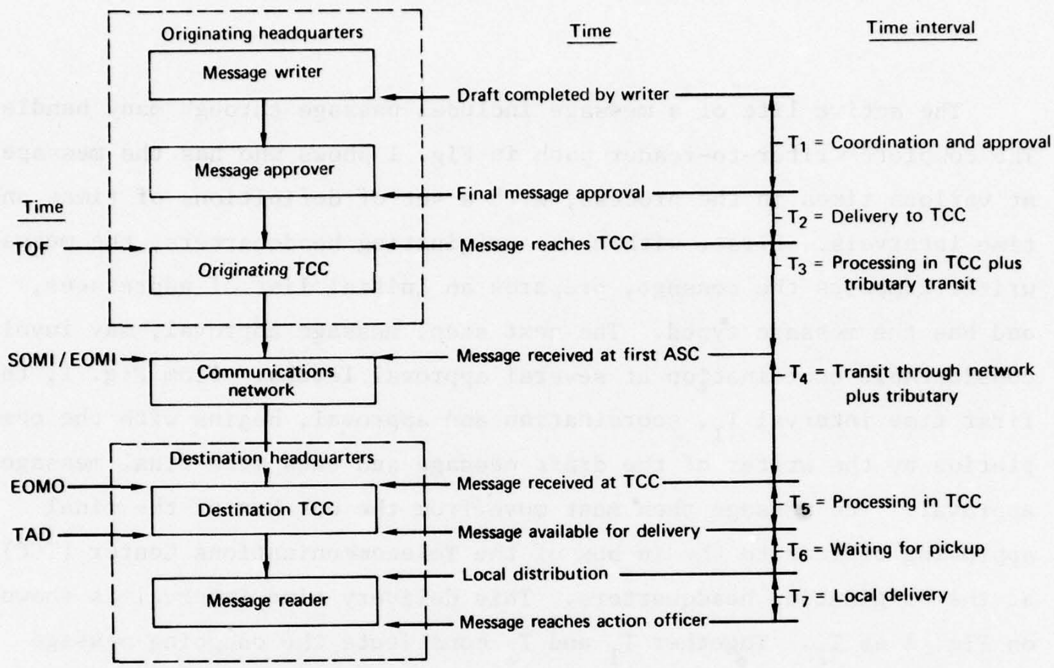


Fig. 1—Writer-to-reader time intervals

at the destination TCC. The end of T_4 is identified as EOMO, end of message out. The destination TCC performs any further required processing, and marks the incoming hard-copy message with time available for delivery (TAD). This additional processing time is measured by the interval T_5. Collectively, T_3, T_4, and T_5 form the communications processing time.

The message is placed in the out box of the TCC, awaiting delivery via interoffice mail to the headquarters of the addressee. The time spent waiting for pickup is measured by the interval T_6. Finally, the message moves via local delivery, such as the base mail service, to the addressee's headquarters, then by another delivery step to the office or desk of the addressee. The time for these delivery processes is measured by T_7. The administrative processing time at the destination is the combination of T_6 and T_7.

If a message is of Flash or higher precedence level, an operator at the destination TCC may call and request that the message be picked

up immediately. Under certain circumstances the operator may read the message over the telephone. Expedited delivery of a hard copy may or may not occur. If it does not, then the destination administrative processing time will appear anomalously long compared to the actual speed with which the system functioned. We shall return to this point under the discussion of outliers.

The ACCWRS report,[5] described more fully in Appendix A, measured the message processing times at 13 TCCs of the AUTODIN I system during parts of 1975 and 1976. At each station, outgoing messages were marked with time indicators from which T_1, T_2, and T_3 could be determined, and incoming messages were marked to determine T_5, T_6, and T_7. Since an outgoing message could go to, or an incoming message arrive from, a TCC other than one of the specified 13, a message could not be traced through its entire path. Thus, there are no measurements of T_4, and no correlation between the messages of the outgoing set and those of the incoming set. The set of incoming messages is much larger than the set of outgoing messages, especially for high precedence traffic, indicating the large number of possible sources for such messages. (There are about 765 TCCs in AUTODIN I that may originate messages which then arrive at the 13 TCCs participating in ACCWRS.)

The SNAPS report,[3] described more fully in Appendix B, measured two of the three processing times within the communications portion of AUTODIN. It provides statistics on T_3 and T_4, but the definitions used in Ref. 3 automatically set T_5 equal to zero. The values measured for T_3 (the only common interval) by the SNAPS and ACCWRS studies are grossly comparable.

We next describe the AUTODIN I system itself, to make clear what communications paths and handling procedures are actually represented in the data assembly.

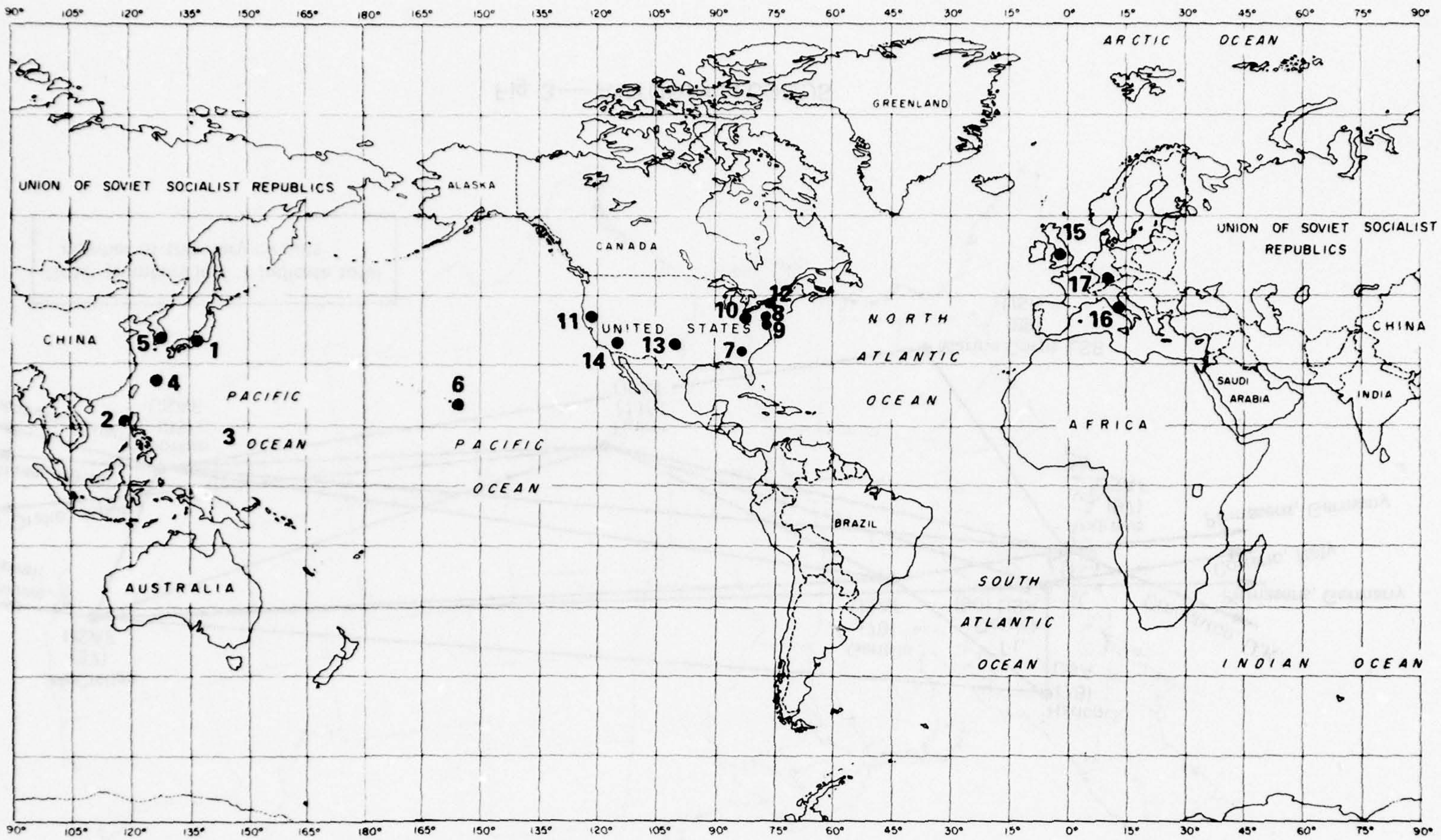
III. DESCRIPTION OF AUTODIN I

AUTODIN I consists of 17 Automatic Switching Centers (ASCs) and approximately 80 Interswitch Trunks (ISTs) connecting the ASCs to each other. Figure 2 shows how the 17 ASCs are distributed throughout the Pacific, the Continental United States (CONUS), and Europe. AUTODIN I is managed by the Defense Communications Agency (DCA). Associated with the ASCs and ISTs are approximately 765 Telecommunication Centers managed by separate services and agencies (Air Force, Army, Navy, and others).[6] These TCCs are generally considered part of the network. The number of TCCs and the size of the headquarters they serve constantly change because of budgetary factors and new military requirements, and the number 765 should only be regarded as valid for February 1977.

Telecommunications Centers are located at or near military headquarters, but are not under their operational control. Each TCC is tied through tributary circuits (subscriber trunks) to one or more ASCs. Tributary circuits include HF radio, microwave radio, buried coaxial cable, submarine cable, and satellite links.[7,8] These circuits have bandwidths ranging from 75 to 9600 Hz, adequate for the transmission of 100 to 12,000 words per minute.

Figures 3, 4, and 5 show the 17 ASCs and some of the approximately 80 IST interconnections in the CONUS, European, and Pacific areas, respectively. The ISTs have channel bandwidths from 1200 to 9600 Hz, adequate for the transmission of roughly 1500 to 12,000 words per minute. Also shown in these figures is the total number of tributary circuits connected to each ASC, as well as the organization responsible for operating and maintaining each ASC.

In Table 1, derived from Ref. 6, we show for each ASC the number of tributary circuits which serve each agency, as well as the total number per ASC. Since TCCs may be connected to more than one ASC, the total number of circuits (1153 as of February 1977), exceeds the estimated number of TCCs (765 as of February 1977). Management responsibility for the tributaries is shared between the two services (unless the TCC and ASC happen to be operated by the same service).



PACIFIC

1 - Camp Drake, Japan
2 - Clark Air Base, Philippines
3 - Finegayan, Guam
4 - Ft. Buckner, Okinawa
5 - Taegu, Korea
6 - Wahiawa, Hawaii

CONUS

7 - Marine Corps Logistic Support Base Atlantic, Albany, Ga.
8 - Andrews Air Force Base, Md.
9 - Ft. Detrick, Md.
10 - Gentile Air Force Station, Ohio

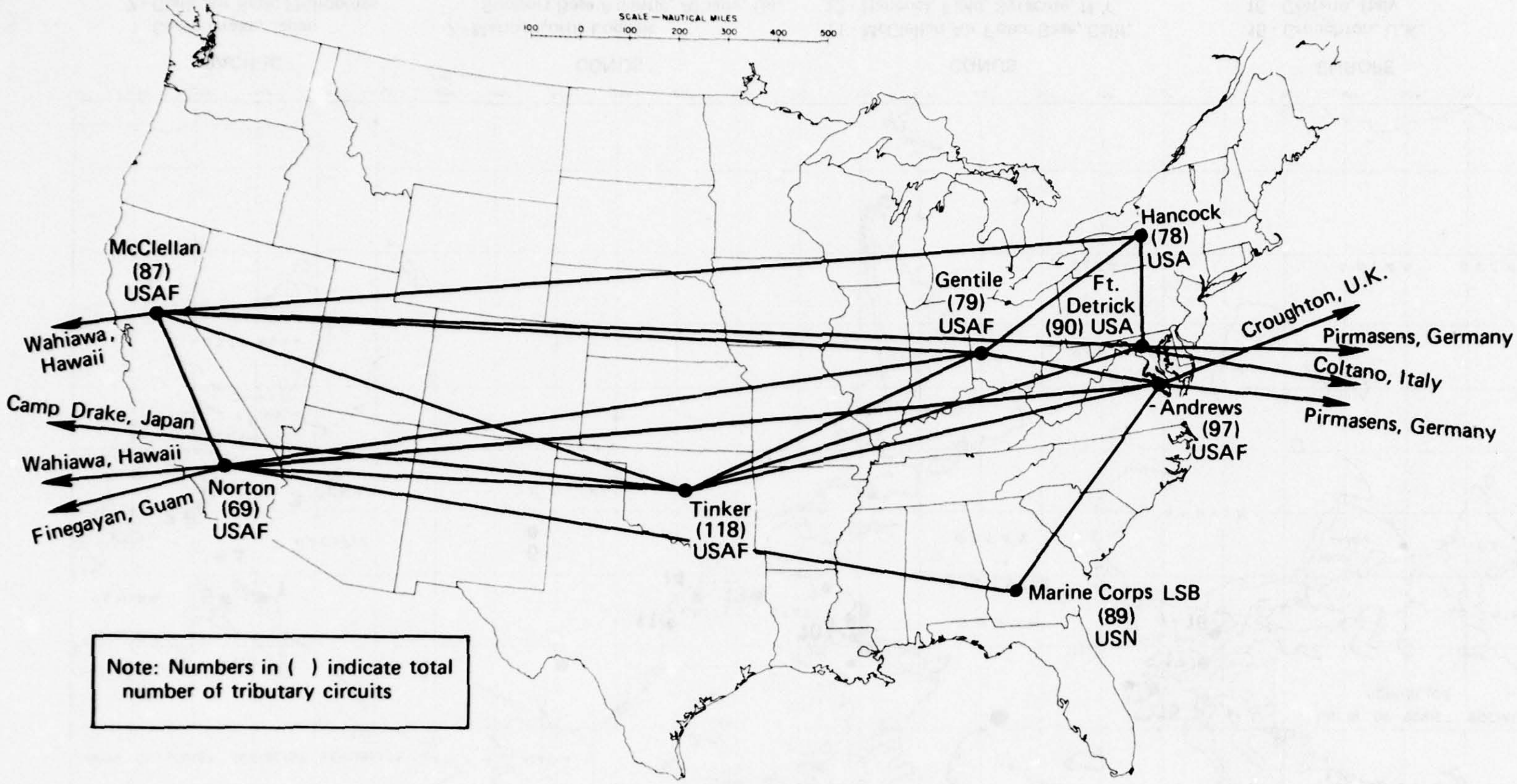
CONUS

11 - McClellan Air Force Base, Calif.
12 - Hancock Field, Syracuse, N.Y.
13 - Tinker Air Force Base, Okla.
14 - Norton Air Force Base, Calif.

EUROPE

15 - Croughton, U.K.
16 - Coltano, Italy
17 - Pirmasens, Germany

Fig. 2—Worldwide locations of AUTODIN automatic switching centers



Note: Numbers in ( ) indicate total number of tributary circuits

Fig. 3— AUTODIN in CONUS

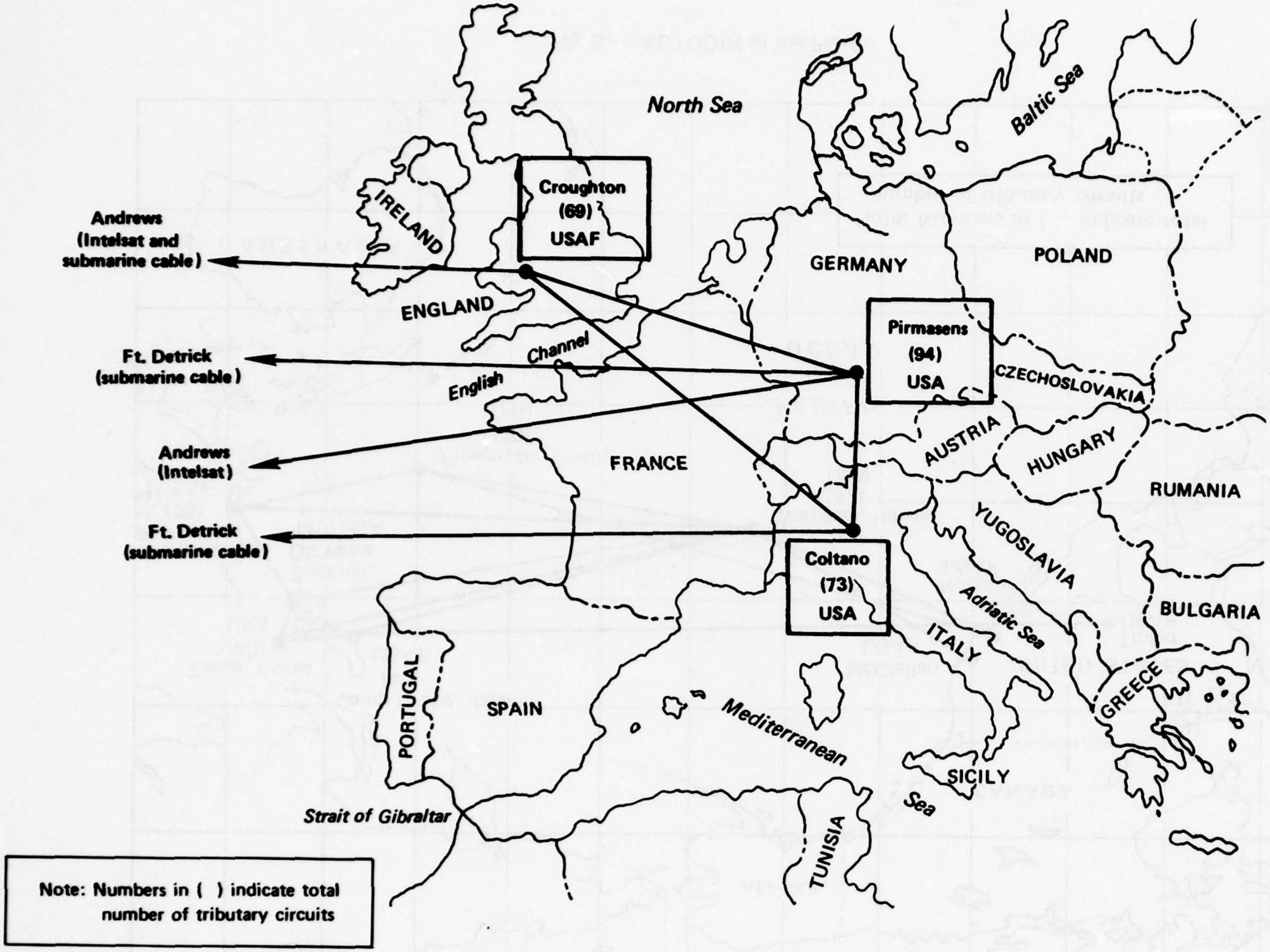


Fig. 4 — AUTODIN in Europe

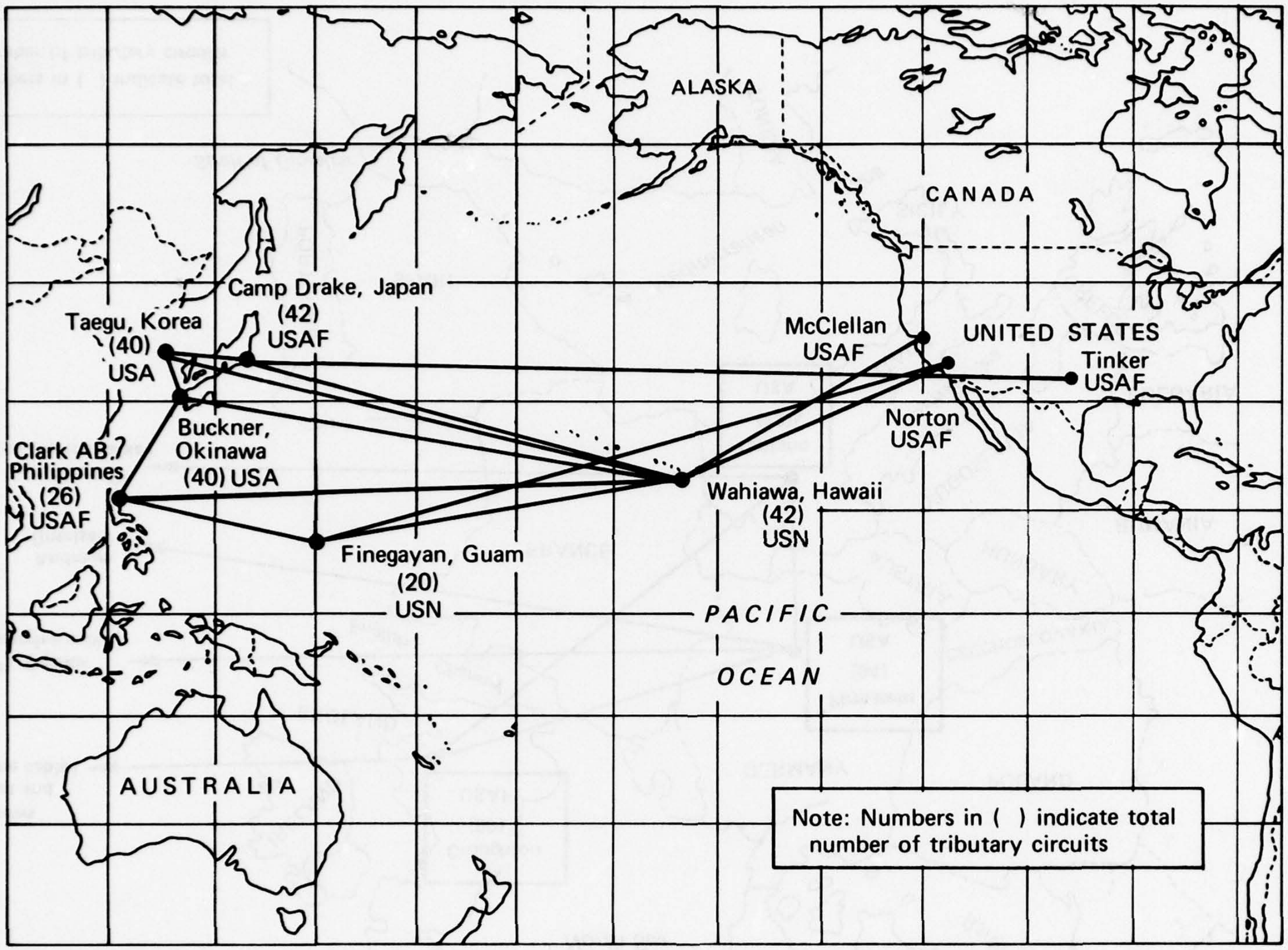


Fig. 5— AUTODIN in the Pacific

Table 1

NUMBER OF TRIBUTARY CIRCUITS CONNECTED TO EACH ASC

ASC Location	Agency Served by Tributary Circuit[a]				
	Air Force	Army	Navy	Other	Total
Andrews Air Force Base, Md.	18	12	36	31	97
Marine Corps Logistic Support Base Atlantic, Albany, Ga.	25	23	28	13	89
Camp Drake, Japan	12	9	17	4	42
Clark Air Base, Philippines	10	1	11	4	26
Coltano, Italy	29	23	12	4	73
Croughton, U.K.	31	13	20	5	69
Finegayan, Guam	5	0	13	2	20
Fort Buckner, Okinawa	14	13	12	1	40
Fort Detrick, Md.	12	28	18	32	90
Gentile Air Force Station, Ohio	29	17	8	25	79
Hancock Field, Syracuse, NY	17	21	21	19	78
McClellan Air Force Base, Calif.	39	9	26	13	87
Norton Air Force Base, Calif.	27	12	21	9	69
Pirmasens, Germany	38	36	10	10	94
Taegu, Korea	12	23	5	0	40
Tinker Air Force Base, Okla.	55	24	9	30	118
Wahiawa, Hawaii	10	5	21	6	42
Total	383	274	288	208	1153[b]

[a] As mentioned earlier, these are also referred to as subscriber trunks. They connect the TCCs to the ASCs and the agency shown manages the TCC.

[b] Since the number of TCCs is constantly changing, the number of tributary circuits is variable. The data on this table are as of February 1977.

The ASCs can operate in either of two modes, message switching or circuit switching. Message switching is a "store and forward" mode in which messages may be held for several minutes at each ASC. Thus, there is no real-time continuous message path through the net of ASCs. AUTODIN routinely handles message traffic in the message switching mode. The circuit switching mode, which does provide a path through the entire ASC net, can enable the CONUS system to handle voice traffic from AUTOVON or AUTOSEVOCOM (AUTOmatic SEcure VOice COMmunications). We will be concerned only with the message switching mode in this report. The words "messages," "traffic," and "message traffic" are used interchangeably in the AUTODIN I literature and in this report.

Messages transmitted through AUTODIN I are characterized by type, precedence, and classification. Three types of messages are handled by the system--narrative text messages (teletype), data on punched cards (data pattern), and messages on magnetic tape. The precedence levels, in decreasing order, are: Emergency Command Precedence (ECP), Critical, Flash Override, Flash, Operational Immediate, Priority, and Routine. We shall refer to Flash and higher levels simply as Flash, and shall call Operational Immediate simply Immediate; classification levels are Top Secret and Special Category, Secret, Confidential, Encoded for Transmission Only (EFTO) which is handled as unclassified, and Unclassified.

Reference 3 (SNAPS) gives traffic statistics for a randomly selected day (RADAY 183, 1 July 1976). Since no special event occurred on that day, we may treat it as representative of the normal behavior of the system traffic. If a crisis were to occur, we could anticipate increases in the number of higher precedence, more highly classified messages, although, more typically, crises increase telephone traffic. Table 2, taken from Ref. 3, displays the number of messages by type, precedence, and classification, and also measurements of the average message length.

According to Table 2, slightly more than half (56 percent) of the messages are narrative, the remainder (44 percent) data. A very small fraction (0.14 percent) are of Flash or higher precedence, nearly 8 percent Immediate, 38 percent Priority, and 54 percent Routine. Thus, most of the messages belong to lower precedence levels, and their prompt

Table 2

MESSAGE TRAFFIC STATISTICS,
RADAY 183/1976

	Number of Messages	Percent
Type		
Narrative	123,267	56.32
Data pattern	93,685	42.81
Magnetic tape	1,899	0.87
Total	218,851	100.00
Precedence Level		
Flash and higher	316	0.14
Immediate	17,153	7.84
Priority	83,213	38.02
Routine	118,169	54.00
Total	218,851	100.00
Classification		
Top Secret/Special	577	0.26
Secret	3,143	1.44
Confidential	10,245	4.68
EFTO	20,170	9.22
Unclassified	184,716	84.40
Total	218,851	100.00
Average Length	Line Blocks	
ECP, Critical	7	
Flash	10	
Immediate	18	
Priority	42	
Routine	47	

delivery will be of relatively less military importance. About 16 percent of the messages are classified. These should be associated with higher precedence levels and hence should have their delivery speeded, but may be slowed by encoding operations. Since we lack data, we cannot evaluate these effects.

More extensive message length statistics are presented in Appendix B, Figs. B-9 through B-12. The lengths are measured in line blocks. A line block is one full line of 80 characters and/or spaces. We see from Table 2 that on the average, the higher the message precedence, the shorter the message length. Also, from additional data in Ref. 3,

about 22 percent of the line blocks are narrative and 78 percent are data. We deduce from the relative numbers of narrative and data messages, and their relative lengths in line blocks, that on the average, data messages are about 4.5 times as long as narrative messages.

Messages may have more than one addressee. From Ref. 3, the volume of traffic handled by AUTODIN I on an average day consisted of about 218,000 messages entering the ASCs from all the tributaries and about 416,000 messages exiting the ASCs via all tributaries. This indicates an average of 1.9 addressees per message entering the network. Furthermore, certain messages are destined for TCCs which are linked to the same ASC as the originating TCC, so they never enter an interswitch trunk, while other messages may travel through several ISTs before reaching the destination TCC. Again from Ref. 3, on a typical day there are about 312,000 messages entering and leaving ASCs via ISTs.

Furthermore, the recipient TCCs may have to distribute a message to several addressees at the recipient base. Duplicating and marking copies can cause significant increases in the TCC processing time T_5, and the delivery to the numerous addressees can produce a major increase in the administrative delay time T_7.

This completes our description of the general AUTODIN I system. We shall now consider the standards toward which the operating system aspires.

IV. AUTODIN OPERATING STANDARDS

AUTODIN-related standards fall into two major categories--those concerning the reliability of the hardware and those concerned with the speed of service. The first set measures whether the system is or is not functioning. This set is of primary concern to system designers and operators. The second is a measure, from the user's viewpoint, of how well the system functions when it is supposedly in operation. Each set is regarded as a long-term average.

RELIABILITY STANDARDS

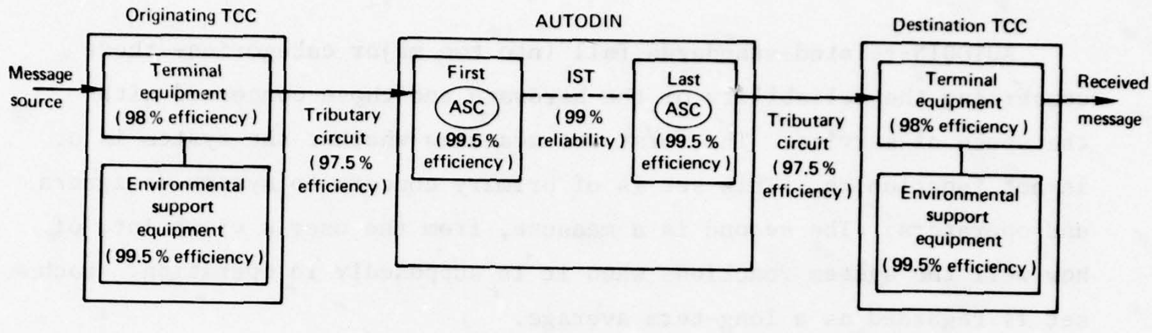
Figure 6 shows the equipment configurations for the originating and destination TCCs, the tributary circuits, and the AUTODIN ASC-IST complex. The terminal equipment includes cryptographic and control units, computers, and peripherals such as card readers, punchers, and printers. The environmental support equipment includes all power and air conditioning equipment.

There are two definitions for reliability standards. One of our source documents[9] defines them as reliability_1 and reliability_2. Our second source[10] calls one definition a reliability standard, and the other an efficiency standard. We have chosen the latter terminology as more descriptive. Each standard refers to the total time interval during which data were collected. For the data to indicate if the standard is met, this time interval should be much longer than both the mean time between failures and the mean time to repair.

The difference between an efficiency standard and a reliability standard is apparent from the definitions (Ref. 10, p. 3-3, para. 4):

$$\underset{\text{(percent)}}{\text{Efficiency}} = \frac{\text{(Total Time Interval)-(Planned and Unplanned Downtime)}}{\text{Total Time Interval}} \times 100$$

$$\text{Reliability} = \frac{\text{(Total Time Interval)-(Planned and Unplanned Downtime)}}{\text{(Total Interval)-(Planned Downtime)}} \times 100$$



SOURCE: Ref. 10.

Fig. 6—AUTODIN reliability and efficiency standards

Thus, the efficiency standard measures the fraction of time that the system is actually operating. The reliability standard measures the ratio of the time the system is operating to the time for which it is planned to have the system operate. Thus, the inclusion of planned downtime in the denominator results in reliability standards that are higher than the efficiency standards. If an efficiency standard is set significantly below the reliability standard, it indicates that reliability can be obtained only at the expense of considerable maintenance. If the efficiency and reliability standards are set virtually equal, the equipment is expected to be inherently reliable and to require negligible maintenance.

Figure 6 shows the standards applied to the various elements of the network. All are efficiency standards except the IST. The various elements can be expected to suffer failures independently, since they correspond to different types of equipment which may be widely separated. If there were no redundancy, so the circuit combination of Fig. 6 represented the network, the overall efficiency would be the product of the efficiency of the separate elements, or 88.6 percent if the standards were just met for each element. Thus, almost every piece of TCC equipment and every circuit must be backed up; i.e., there must be appreciable redundancy if a high overall reliability (95 percent or better) is to

be achieved. We have not been able to determine the bases for these reliability and efficiency standards or to locate sufficient data for a meaningful comparison of standards and actual achievement.

It is apparent from Fig. 6 that the tributary circuits are expected to display the lowest efficiency of any portion of the network. Part of the low efficiency may be inherent in the circuits, but at least some tributary circuits may be handicapped by low Restoration Priority (RP), which measures the nominal importance of restoring service on a particular failed link in the National Communication System (NCS). It is defined, with some variations, in Refs. 9, 10, and 11, and described as "A numerical and alphabetical designation establishing a sequence of priorities for the restoration of communications to users of the DCS [Defense Communications System]." According to Ref. 11, the criterion for Restoration Priority 1, for example, requires that the circuit be "essential to national survival under conditions ranging from national emergencies to international crises, including nuclear attack." The reliability standards associated with circuits of different RP are shown in Table 3. Note that lower numbers represent higher priorities. These values are management threshold values and therefore correspond to a level of performance below which intensive management action is required (Ref. 9, p. 3, para. 1).

Table 3

NCS RESTORATION PRIORITY
AND RELIABILITY

RP Number	Reliability Standard (percent)
1B through 1G	99.0
2A through 2I	95.0
3A through 3C	92.0
4A through 4C	90.0
00	80.0

SOURCE: Ref. 9, p. 2, para. 3. Reference 11 defines a 1A category; Refs. 9 and 10 omit it but include a category 4C.

All tributary circuits have an assigned NCS Restoration Priority number. Low restoration priorities reflect less critical circuits. The lower reliability does not result from the use of less reliable circuits, which might have been used, for example, to reduce costs. More likely, the delay in repairing equipment failures of higher RP number, caused by postponing their repair to restore lower RP circuits, results in substantially longer unplanned downtime. The lower reliability standard makes allowance for this delay. In actual practice, circuits with higher RP numbers (and thus with lower management threshold reliability standards) are preempted and used to replace inoperative circuits with lower RP numbers until all services are restored.*

The AUTODIN I efficiency standard of 97.5 percent may not be realizable for tributary circuits whose RP number is greater than 1. We have not located data which give either the number of tributary circuits of each RP number or an analysis of tributary circuit outages as a function of RP number. Thus, we cannot determine the difficulty of meeting the AUTODIN tributary standard.

There are two ways to improve the reliability of communication systems. One is to use more reliable components and the other is to provide redundancy. AUTODIN I has clearly provided redundancy for its Interswitch Trunks. The 17 ASCs could be connected by as few as 16 links. If every ASC were connected to every other ASC, a total of 136 ISTs would be required, and if 100 percent redundancy were required in addition, 272 ISTs would be necessary. The actual number is only 80, but this means that on the average each ASC is connected to four or five other ASCs, providing a considerable number of communication paths.

Several types of transmission media are used for the ISTs. Each medium has its own reliability standard, as indicated in Table 4.

Only some of the transmission media below have reliability standards which meet the 99 percent requirement for ISTs shown in Fig. 6. We know that the vast majority of AUTODIN I ISTs employ microwave, tropospheric scatter, submarine cable, or landline connections to meet

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*Private communication from Lt. Col. J. W. Nolan, DCA Operations, Code 500.

Table 4

IST RELIABILITY BY TRANSMISSION MEDIUM IN ORDER OF INCREASING FREQUENCY

	Reliability Standard (percent)
HF Radio	95
VHF Radio	98
Microwave, tropospheric scatter, submarine cable, landline	99
Satellite, Phase I (UHF, SHF)	85
Satellite, Phase II (UHF, SHF)	95
Satellite, millimeter wave	?

SOURCE: Refs. 9 and 10, except for the last line.

the standard. However, we do not know what small percentage of the network involves transmission media that fall short of the standard. The satellite links carry the bulk of IST traffic to and from the CONUS today, and will probably carry a greater percentage of this traffic in the future, but the overseas traffic is small compared to the total AUTODIN I IST traffic, which is primarily among ASCs located within the CONUS.

If we wish to achieve the indicated 99 percent IST reliability by the use of redundancy, then it is clearly advisable to use media which have different causes of failure. Thus, one could use two different satellites between a pair of ASCs, or a satellite and a submarine cable, or a microwave link and a buried landline, or HF radio and satellite, or many other combinations.

Associated with the equipment reliability standards is a message rejection rate standard. The criteria for rejecting a message are broadly stated in Ref. 10, p. 3-4, para. 6, as "improper message preparation and other deficiencies at the originating AUTODIN I terminal." More specifically, from Ref. 8, p. 4-59, para. 460, messages are rejected when header format or end-of-message validation errors occur. The rejection standard, defined as the ratio of the number of messages rejected to the total number of transmissions, is 2 percent for all

terminals in the United States and for some overseas terminals, and is 4 percent for the remaining overseas terminals. Since errors in the message which result in message rejection may be caused by the onset of equipment failure, we expect that message rejection rates and reliability will be correlated. Also, since rejection of a message necessitates retransmission, the message rejection rate affects speed of service.

A serious limitation of the reliability standard is that it describes only the long-term cumulative outage behavior of the system. We have not found readily available information on the number of outages, the geographic or temporal distribution of occurrence and cause, and the distribution of outage durations. Without such information, one cannot optimally choose among the numerous techniques available to improve reliability. These distributions are closely related to the speed of service, so we shall next consider the speed of service standards.

SPEED OF SERVICE STANDARDS

The complete writer-to-reader message path in Fig. 1 defines the seven time intervals that determine the complete delivery time. The communications system forms the central section of the path, including the transmitting TCC, the communications network, and the destination TCC. It thus nominally includes the time intervals T_3, T_4, and T_5. However, AUTODIN I defines its speed of service standards in such a way that T_5, the processing time in the destination TCC, is set equal to zero. This is certainly not true in general. It may be expected that the handling time in the destination TCC, where little processing is required, will be small compared to the processing time in the originating TCC plus the transmission time through AUTODIN I, but for Flash and Immediate messages it is found (see Appendix A, Table A-3), that the time T_5 is definitely nonnegligible compared to any of the other six time intervals.

The speed of service standards are given in terms of a set of initiation times for the intervals. The standards for the several precedence levels are shown in Fig. 7, which also defines the various times. The first is the Time of File (TOF). This is a date/time group which

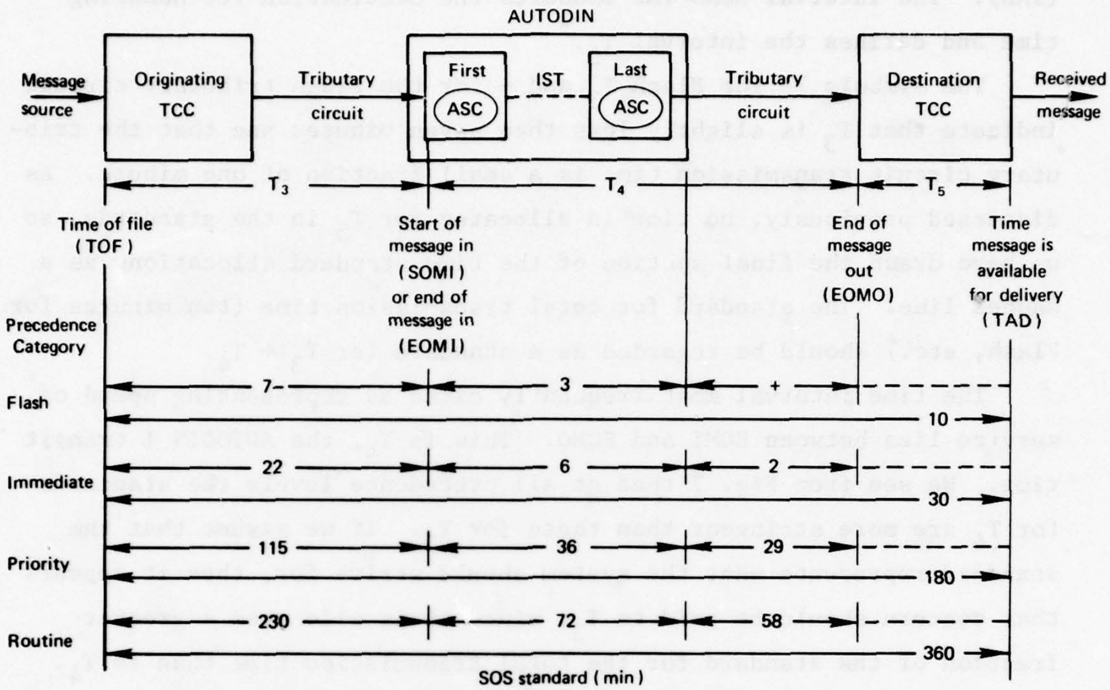

Fig. 7--AUTODIN speed of service standards

is supposed to be stamped on the message when it enters the originating TCC, and thereafter becomes part of the header on the transmitted message. The next time point is the time at which the message starts into the first ASC, Start of Message In (SOMI), which is not too significant. The second reference time point, the time at which the message has been entirely received at the first ASC and acknowledged via the tributary to the transmitting TCC, is called End of Message In (EOMI). For short messages, or long messages sent over a high speed tributary, EOMI ≅ SOMI. The time interval TOF-EOMI measures the originating TCC handling time and defines the interval T_3. The third reference time, End of Message Out (EOMO), is the time at which the message is entirely received and acknowledged at the destination TCC. The time interval EOMI-EOMO measures the AUTODIN transit time and defines the interval T_4. Finally, the time at which the message is completely processed by the destination TCC defines the last reference point, the Time Available for Delivery

(TAD). The interval EOMO-TAD measures the destination TCC handling time and defines the interval T_5.*

The symbols 7- for Flash T_3 and + for the Flash tributary circuit indicate that T_3 is slightly less than seven minutes and that the tributary circuit transmission time is a small fraction of one minute. As discussed previously, no time is allocated for T_5 in the standards, so we have drawn the final section of the time standard allocations as a dashed line. The standard for total transmission time (ten minutes for Flash, etc.) should be regarded as a standard for $T_3 + T_4$.

The time interval most frequently cited as representing speed of service lies between EOMI and EOMO. This is T_4, the AUTODIN I transit time. We see from Fig. 7 that at all precedence levels the standards for T_4 are more stringent than those for T_3. If we assume that the standard represents what the system should strive for, then it appears that concern should be paid to T_3, since it is allocated a greater fraction of the standard for the total transmission time than is T_4.

The values cited above for the standard for total transmission time, as taken from Ref. 10, do not require that all messages be processed within the indicated time. They require that 95 percent of the narrative messages (56 percent of the total number of messages) and 96 percent of the data pattern and magnetic tape messages (the remaining 44 percent) meet these time requirements. This allowance for long messages will be discussed later.

We next discuss in detail the statistical properties of the data we have collected on the AUTODIN I system.

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*The numerical values given for the interval TOF-SOMI or EOMI (T_3) are taken from Ref. 9, p. 3, para. 6c; for the interval SOMI or EOMI-EOMO (T_4) from Ref. 9, p. 3, para. 6b. The standard for the full-length interval TOF-TAD is from Ref. 9, p. 3, para. 6a, and also from Ref. 10, p. 3-6. Since Refs. 9 and 10 use different definitions, we have used the additional information to estimate the tributary circuit transmission times.

V. WRITER-TO-READER DELAYS

STATISTICAL ANALYSIS OF THE DATA

This section describes certain statistical properties of the data that have been accumulated on speed of service of communications systems. It draws on the Army Communications Command Writer-to-Reader Study (ACCWRS),[4,5] and on the DCA Switch Network Analysis Profile System (SNAPS) report.[3] The ACCWRS study (Ref. 5 is the first of a planned series of reports), conducted at Fort Huachuca, Arizona, during 1975 and 1976, collected records of T_1, T_2, T_3, T_5, T_6, and T_7 at 13 Army TCCs throughout the world. This study is described in Appendix A. As shown in Table A-1, 1,662,144 time interval records were incorporated in the study. In contrast, the SNAPS reports, one of which is described in Appendix B, present speed of service (T_3 and T_4) for the entire AUTODIN I system. We use SNAPS data for seven sample days during the interval September 1974 to March 1975 (first Thursday of each month), a total of 2,411,299 messages. These data also appear in Ref. 4. These collections provide the data base for our investigation. Most of our effort has been devoted to Flash messages. We always use the term Flash to mean Flash or higher precedence level.

We found that T_4, the electronic transmission time through AUTODIN I, is small--almost negligible--compared to the other time intervals. At the median level, the administrative processing delays and communications processing delays are roughly comparable. At high percentiles, corresponding to those Flash messages which take several hours to traverse the complete path from writer to reader, the administrative delays, particularly T_6 and T_7--pickup and delivery at the recipient's base--are by far the dominant contribution to the total writer-to-reader transmission time. We next give the data and statistical analysis which has led us to these conclusions.

The data analyzed and published by the Army Communications Command[4,5] cover the period 1 April to 30 June 1975, and include about 522,000 time interval samples. A set of rejection criteria eliminated about one percent of the records as excessively long (see Table A-2). The records were categorized by precedence level. For each level, the

data were processed to yield the mean and standard deviation for each time interval for the entire sample. Also, for each time interval, the mean delay was calculated for each day, and then the standard deviation of this set of daily means was determined. The 95 percent tolerance intervals (the time exceeded by only five percent of a sample) were calculated for the complete set of messages and for the daily means, using the formula $T_{95} = \bar{T} \pm 1.96\sigma$. (If the formula lower limit is less than zero, zero is used.) This formula, which holds for a normal distribution only, states that 2.5 percent of the values lie more than 1.96 standard deviations above the mean, and correspondingly below. It is reasonable for the daily means to be represented by a normal distribution. We discuss the message set distribution below. The results for Flash messages, abstracted from Table A-2, are presented in Table 5. All the 95 percent tolerance levels below the means of the complete set of messages were zero and are not shown.

Table 5 both provides answers and raises questions. It is immediately clear that the administrative handling times T_1, T_2, T_6, T_7 provide much greater contributions to the average total writer-to-reader

Table 5

ACCWRS FLASH SPEED OF SERVICE

Time Interval	Mean Value $\bar{T}$ (hr)	Standard Deviation σ (hr)	95% Tolerance Interval (Time Exceeded by Only 5% of a Sample with 95% Confidence) T_{95} (hr)	Standard Deviation of Daily Means σ_D (hr)	95% Confidence Interval for Daily Means (hr)
T_1	1.16	4.03	9.07	0.66	0.00 to 2.46
T_2	1.50	3.18	7.73	0.52	0.49 to 2.51
T_3	0.25	0.51	1.24	0.08	0.09 to 0.42
T_5	0.23	1.43	3.03	0.17	0.00 to 0.57
T_6	2.92	6.11	14.89	0.78	1.40 to 4.44
T_7	3.54	10.37	23.86	1.31	0.98 to 6.10

SOURCE: Ref. 5.

time than do the TCC processing times T_3 and T_5. It is also apparent from the large ratios of σ to $\bar{T}$ that the data must display considerable spread. The relatively small value of the standard deviation of the daily means compared to the means themselves implies that the message statistics do not vary much day to day, and the rejection criteria have eliminated any absurdly long message delays, most of which probably correspond to misdated or misrouted messages. Since the delay cannot be less than zero, the large value of $\sigma/\bar{T}$ indicates that at least the fast delivery portion of the message set ($T < \bar{T}$) cannot be well represented by a normal distribution. The mean is not likely to be near the mode. It is much more probable that the message distribution displays strong skewness, with a relatively small number of long delay messages making a much larger contribution to the mean than a large number of messages with short delivery time.

To develop a better picture of the statistics than can be deduced from consideration of mean and variance, and also to ascertain the size of the data base, we asked the Army Communications Command (ACC) to sort the data base to obtain the distribution. They chose only one of the 13 TCCs and a 0.25 hour bin size. The message sample size, as shown in Table A-4 of Appendix A, averages only 14 outgoing Flash messages for this TCC, but about 495 incoming Flash messages. Table 6 summarizes the results for narrative Flash traffic.

In view of the small sample size of outgoing Flash message traffic, the data for the first three time intervals of Table 6 may be somewhat more clearly expressed as follows. For the 12 messages for which T_1 is available, 6 were processed in less than 15 minutes, 3 took between 15 and 30 minutes, 1 about 3 hours, 1 about 7 hours, and 1 over 8 hours. For the 14 messages of the T_2 sample, 9 were processed in less than 15 minutes, 2 took 15 to 30 minutes, 1 about 1 hour, 1 near 2.5 hours and 1 about 6 hours. All 15 messages had T_3 less than 15 minutes. Since the mean T_1 calculated from Table 6 is about 1.75 hours, and the mean T_2 is about 1 hour, we see that the mean is strongly dominated by the few messages with long delay times (3 out of 12 for T_1, 3 out of 14 for T_2). Similar conclusions can be drawn for the incoming times T_6 and T_7, for which the means lie respectively near the 78

Table 6

CUMULATIVE DISTRIBUTION FOR ONE TCC[a]
FOR NARRATIVE FLASH MESSAGES

Percent of Messages	Time Interval (hr)[b]					
	T_1	T_2	T_3	T_5	T_6	T_7
100	8.50	6.00	0.25	5.50	70.00	60.00
99	(c)			0.50	56.25	47.25
98					54.50	31.75
95	7.25	2.50		0.25	32.75	12.75
90	3.25	1.25			13.00	4.00
80	0.50	0.50			4.50	2.25
75					1.00	1.25
70		0.25			0.50	0.75
60					0.25	0.25
50	0.25					

[a]For the April to June 1975 time period.

[b]ACC selected a fixed 0.25 hr bin size.

[c]Blanks indicate that the sample size is too small to evaluate the distribution, or the distribution is obscured by the 0.25 hr bin size.

percent point and the 85 percent point of the distribution. We conclude that our previous deductions are correct, that the distribution of the actual data is severely skewed, that it is not well represented by a normal distribution, and that the mean delay is not a suitable measure for the speed of service of the system. Despite the large means, more than half the messages are processed in less than 15 minutes for each time interval. The communications system serves the majority of the users much better than would be indicated by the means.

We also obtained from the ACC a breakdown of the sample size and mean times for each TCC for the time interval covered by Ref. 5. The data for Flash traffic are shown in Table 7. The entries display great variability, with most of the traffic originating in TCC 6 and most being received by TCCs 9 and 11. We have no information on the distributions and cannot tell if the means are representative, but we would

Table 7

ACCWRS FLASH SPEED OF SERVICE DATA BY TCC
(hours)

TCC	T_1 n[a]	T_1 Mean	T_2 n	T_2 Mean	T_3 n	T_3 Mean	T_5 n	T_5 Mean	T_6 n	T_6 Mean	T_7 n	T_7 Mean
1	(b)											
2							5	0.17	4	0.17	3	3.20
3							1	1.35	1	1.73	1	1.25
4	2	0.12	2	0.30	2	0.06	2	0.10	2	0.16	2	0.10
5												
6	49	1.06	54	1.13	50	0.19	22	1.09	24	1.80	20	0.70
7	2	0.02	1	1.82	2	1.92	3	0.02	3	4.50	3	1.41
8												
9	4	1.48	5	4.99	8	0.24	105	0.25	76	1.12	99	3.89
10							32	0.05	27	5.70	15	1.08
11	3	3.92	3	2.88	3	0.17	190	0.15	156	3.54	136	4.20
12							3	0.05	3	4.60	3	1.13
13												
Total Average	60	1.16	66	1.50	65	0.25	363	0.23	296	2.92	282	3.54
Values not used	0		0		3@24 hr		3@26 hr		0		1@1 mo.	
Total no. samples and mean	60		66		68	(1.30)	366	(0.44)	296		283	(6.08)

[a] n = number of messages

[b] The blanks indicate no Flash messages were handled.

expect the same type of skewed distribution. The effects of pruning the data to eliminate absurd values are also shown in Table 7. The last line shows the great increase in the means when the stray values are included. Thus, the mean of T_3 is increased from 0.25 to 1.30 when the three 24-hour messages (probably misdated) are used in the calculation.

Our other source of data was one of seven DCA SNAPS reports,[(3)] described in Appendix B. This report provides values of T_3 and T_4 on RADAY 183 (1 July), 1976. The distributions for Flash traffic are

presented in Figs. 8 and 9. We do not have information on the day-to-day variation among the seven days, but the sample size is very large and there is no reason to expect a secular trend during the seven-month period.

Figures 8 and 9 again display strongly skewed distributions. The indicated means for T_3 (28 minutes) and T_4 (3.3 minutes) both lie near the 85 percent points of the distributions. We note that if the long delay messages (more than 360 minutes) of T_3 are omitted, the mean for T_3 reduces to 17 minutes if the upper limits of the histogram blocks are used to calculate the mean, and to about 12.5 minutes if the midpoints of the blocks are used (180 to 360 represented by 270, etc.). For T_4, we obtain a mean of 3.73 minutes using the upper limits, 2.5 minutes using the midpoints. The last 3 percent of the messages displayed in Fig. 9 (these with T_4 greater than 10 minutes) contribute 32 percent of the mean when upper limits are used, 38 percent when midpoints are used. We again deduce that the means are very poor representations of the distributions. We also observe that T_4 displays much smaller means, and a distribution concentrated toward much smaller

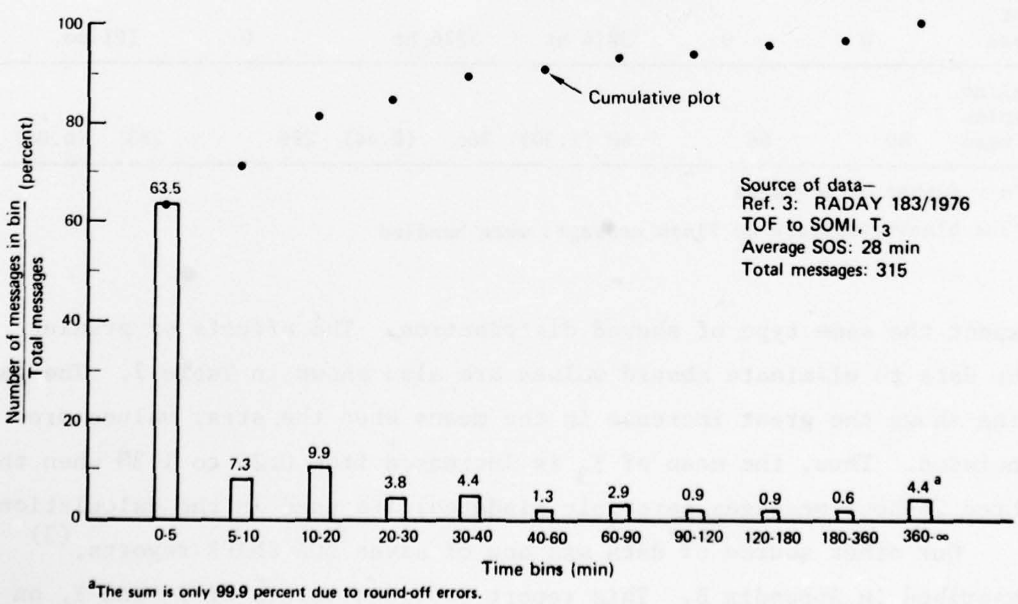
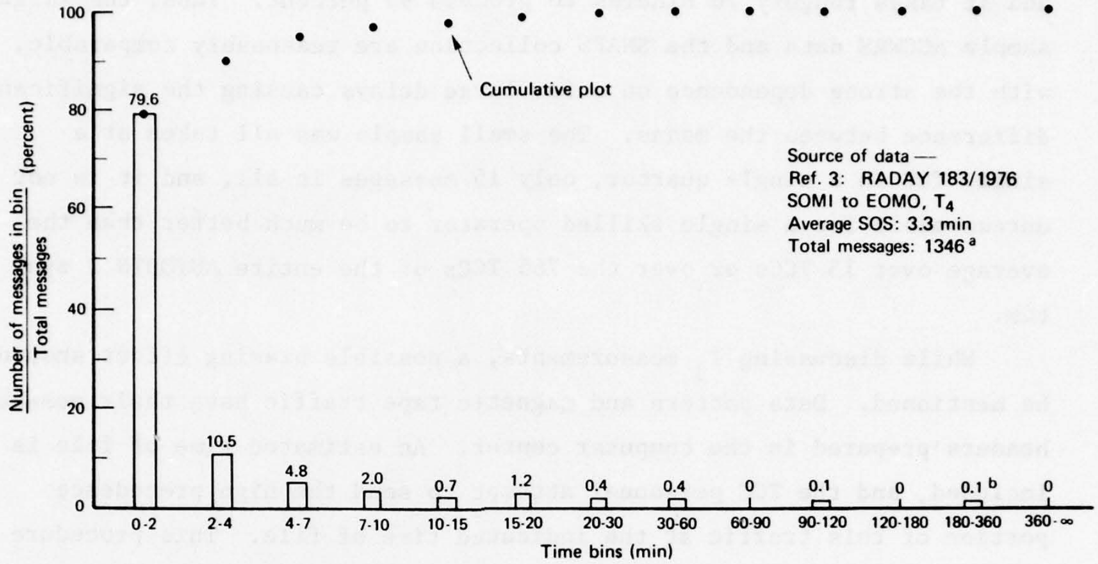


Fig. 8—Flash speed of service histogram for T_3



[a] The 315 messages of Fig. 9 must have had an average of 4.27 addresses each, resulting in 1346 messages transiting AUTODIN.

[b] The sum is only 99.8 percent due to round-off errors.

Fig. 9—Flash speed of service histogram for T_4

values, than any other time interval. Nearly 80 percent of the messages have T_4 less than 2 minutes, and about 90 percent have T_4 less than 4 minutes.

The only time interval in common between the ACCWRS and SNAPS studies is T_3. They use exactly the same definition. We observe that the ACCWRS data for T_3 represent faster processing than the SNAPS data. For the 15-message sample of Table 6, all the messages were processed in less than 15 minutes. The larger sample of Table 5 shows a mean of 15 minutes and a 95 percent value (calculated for a normal distribution) of 74 minutes. If we assume that the mean lies at the 83 percent point and the distribution is similar to the SNAPS distribution of Fig. 8, the 95 percent point would be at about three times the mean, or 45 minutes. For the SNAPS data of Fig. 8, the mean is 38 minutes, about 75 percent of the messages are processed in 15 minutes, and it took 180 minutes to process 95 percent. If we exclude the messages which took over 360 minutes and use midblock values as representative, the mean

is about 12.5 minutes, about 84 percent are processed in 15 minutes, and it takes roughly 70 minutes to process 95 percent. Thus, the large sample ACCWRS data and the SNAPS collection are reasonably comparable, with the strong dependence on a few large delays causing the significant difference between the means. The small sample was all taken at a single TCC in a single quarter, only 15 messages in all, and it is not unreasonable for a single skilled operator to be much better than the average over 13 TCCs or over the 765 TCCs of the entire AUTODIN I system.

While discussing T_3 measurements, a possible biasing effect should be mentioned. Data pattern and magnetic tape traffic have their message headers prepared in the computer center. An estimated time of file is included, and the TCC personnel attempt to send the high precedence portion of this traffic at the indicated time of file. This procedure skews the actual T_3 time toward smaller values, since the time at which the message actually reached the TCC may be significantly earlier than the indicated file time, resulting in spuriously short apparent processing times. With about 44 percent of total ACC traffic composed of data pattern and magnetic tape (see Table 2), this effect can seriously distort the speed of service distribution for T_3. Legitimate values for T_3 could be obtained if the TOF were inserted by automatic handling equipment when the data pattern and magnetic tape first arrive at the TCC.

We observe that the delay population seems to be divided into two groups. A large percentage of the traffic is processed in time intervals of 15 minutes or less. From Table 6, we see that administrative handling times of 15 minutes cover 50 percent of the T_1 values, 70 percent of the T_2 values, and 60 percent of the T_6 and T_7 values. Actually, T_1 and T_2 represent very small samples from a single TCC and should not be taken too seriously. For operational handling times, 15 minutes cover about 75 percent of T_3 values (Fig. 8), 98 percent of T_4 values (Fig. 9), and 95 percent of T_5 values (Table 5). If we extend the delivery interval to 30 minutes, the percentages for T_1 through T_7 are 80, 80, 85, 99.6, 99, 70, and 65. For higher percentages, the time intervals begin to stretch out very rapidly, indicating a change in

character of either the messages or the handling procedures. We shall refer to this group of messages with long handling times as the outliers. As discussed previously, they strongly affect the mean.

It is clear that T_4, the electronic transmission time through AUTODIN I including the destination tributary circuit (incorporating the storage time at each ASC), is small--almost negligible--compared to the other time intervals. This is evident at all percentile levels for which we have data. There is no information on any time interval at percentages below the median, but all the medians themselves are at or below 15 minutes, indicating that the median administrative processing delays (T_1, T_2, T_6, and T_7) are not that much worse than the communications processing delays (T_3, T_5). For higher percentages, the administrative delays, particularly T_6 and T_7, are by far the dominant contributors to the total message writer-to-reader transmission time.

Perhaps various techniques, such as electronic transmission (AMME, MPDS), video display with text editing, interactive conferencing between terminals, and delegation of approval within those headquarters which originate Flash messages, will be required to improve the inordinate amount of time consumed in administrative processing intervals. Neither higher speed transmission on AUTODIN I nor fully automated TCCs will reduce these intervals, since such procedures affect only T_3, T_4, and T_5, which do not contribute significantly to the overall delay when long total delays are considered. It would be convenient if we had to concentrate only on the 17 ASCs of Fig. 2 or just a fraction of the 765 TCCs to improve the system speed of service, but such improvement may require working on all headquarters which handle messages. When these headquarters serve different services and agencies, the problem appears formidable.

We shall next consider how the measured values of the system delays compare to the system standards, and then discuss possible causes for the population of outliers.

MEASUREMENTS VERSUS STANDARDS

The data of Appendix B, derived from Ref. 3, provide enough information about the delay distributions of T_3 and T_4 that we can relate

the measured quantities to the standards presented in Fig. 6. The comparison is shown in Table 8. The standards prescribe the time that it should take for 95 percent of narrative traffic, and 96 percent of total traffic, to transit the indicated time interval. We also show for T_3 and T_4 the standard, the percent of the messages which actually are processed within the standard, and the time taken to process 95 percent of the traffic. Results are given for all precedence levels.

The measurements of Appendix B provide no breakdown above 360 minutes, so we cannot determine the time for 95 percent of the priority or routine messages to transit T_3. We observe that the system comes closer to meeting standards for lower precedence messages than for higher precedence, that the system more nearly meets the T_4 standards than the T_3 standards (actually improving on the T_4 standard for priority and routine), and that the large population of outliers cause the 95 percent points to lie very far out on the distribution and make the speed of service, as measured by the 95 percent point, fall very far below the T_3 standard. The situation is much the worst for T_3 for the Flash messages, where the actual time for 95 percent of the messages to transit is about 25 times the standard. Either the standard is unrealistically low and simply cannot be achieved, or the phenomena which produce the outlier population must be found and corrected.

Table 8

MEASURED TIME VERSUS STANDARDS

	T_3			T_4		
Precedence Level	95% Standard (Min)	Percent within Standard	Measured Time for 95% (Min)	95% Standard (Min)	Percent within Standard	Measured Time for 95% (Min)
Flash	7	66	180	3	85	7
Immediate	22	77	260	8	86	25
Priority	115	79	(a)	65	97	32
Routine	230	84	(a)	130	97	77

[a]Ninety percent of these messages transit T_3 within 360 minutes.

THE OUTLIER POPULATION

We have established that the system serves the majority (60 to 70 percent) of the users quite well, with delay times in any of the seven intervals below 15 minutes for Flash messages. However, the remainder of the messages, the outliers, display much greater delays. Possible causes and conceivable treatments are discussed next.

We first make a distinction between real outliers and those for which the delay is only apparent. The latter occur when the delay is actually short, but errors in the recording of the times, or deviations from the normal message handling techniques, make it appear much longer. These are frequently consequences of clerical errors, such as entering the wrong month, the wrong day of the month, or incorrect time of file, or some other nominally minor error which generates an inordinately long apparent time interval which has no relation to the actual speed of service. As discussed before, the mean value of the time interval T_3 could be increased by a factor of five if such messages are included. Another source of apparent delay, which applies to T_6 and T_7 (waiting for pickup and distribution at destination) for Flash messages in particular, results when the addressee receives the contents of the message via a telephone call from the destination TCC. The usual hard copy then may not be rushed, but sent via routine mail. It may arrive hours or days after receipt of the telephone call. The system has actually functioned extremely well, but the data recording procedures display the hard copy reception time and thus indicate that the system has functioned very poorly. It should be possible to eliminate these apparent delays by automated assignment of the date/time group when the message is received at the TCC, and by recording the time of the telephone transmission if such occurs. These better data gathering procedures would help determine the actual system speed of service.

Clerical errors can also produce long real delays. Such controllable real delays may be produced by mistyped messages or by incorrect destination or routing indicators which require a later retransmission. Other causes of long delay, such as extreme message length, hardware outages, or an excessive number of addressees per message (each

requiring a separate routing indicator) are only partially within the control of the communications personnel, and we shall call them marginally controllable delays.

Message length manifests itself in several ways in its effect on the system speed of service statistics. The transmission time of a message through a tributary circuit is proportional to the message length and inversely proportional to the tributary circuit speed. This relation is shown in Table 9, which gives the transmission time versus circuit speed for message lengths of 10, 30, 100, and 500 line blocks. For low-speed circuits, these transmission times can be quite long. Thus, a 30-line-block Flash message sent via a 75-baud tributary circuit requires 4.2 minutes just for transmission, 1.2 minutes in excess of the standard for T_4, which is supposed to include the final tributary circuit. Since the same 4.2 minutes are required for the tributary circuit at the originating TCC, only 1.6 minutes would be left for all the processing details of the originating TCC (assign a date/time group, list all addressees and provide routing indicators for each, retype the message if necessary, then convert it from hard copy to electronic

Table 9

TRANSMISSION TIME AS A FUNCTION OF MESSAGE LENGTH AND TRIBUTARY CIRCUIT SPEED

Tributary Circuit Speed (bauds)[a]	Approximate Words/Min	Line Blocks[b] Per Min	Message Length (Line Blocks)[c] 10	30	100	500[d]
			Transmission Time (min)			
75	94	7	1.4	4.2	14.	70.
150	187	14	0.70	2.1	7.0	35.
300	375	28	0.35	1.1	3.5	18.
600	750	56	0.18	0.53	1.8	8.8
1200	1500	112	0.09	0.26	0.88	4.4
2400	3000	225	0.04	0.13	0.44	2.2
4800	6000	450	0.02	0.06	0.22	1.1
9600	12000	900	0.01	0.03	0.11	0.55

[a]1 baud ≈ 1 bit per second (bps).
[b]One line block is approximately 80 characters plus spaces.
[c]The message length includes the header and addressee lines.
[d]500 line blocks is the maximum message length allowed on AUTODIN.

format) if the combined speed of service standards for T_3 and T_4 are to be met. This would correspond to a typing speed faster than 300 words per minute. Thus, it can be physically impossible to meet the AUTODIN standards for T_3 and T_4 when the messages are long compared to the average message length, discussed below, and the transmission speeds are low. It is clear from this discussion that either it is necessary to have different standards for different circuit speeds, or the transmission of long messages over low-speed circuits should be minimized if the standards are to be met.

Since message length is a strong producer of outliers, a statistical study of the distribution of message lengths is in order. We have based our investigation on the data in one of the SNAPS reports. Message length histograms, extracted from that report, are given in Appendix B as Figs. B-9 through B-12. Some parameters of the distributions are summarized in Table 10.

We see from Table 10 that the message length (median, average, or 95 percent) increases as the precedence level decreases. Also, the ratio of average to median is higher at lower precedences, and the average lies further out on the distribution for these lower precedences. The ratio of 95 percent to average also increases, demonstrating that there are many extremely long messages at low precedence levels. We do not have the separation, but suspect that many of these long messages are voluminous data-card transmissions.

Table 10

DISTRIBUTION OF MESSAGE LENGTHS

Precedence	Median Length (Line Blocks)	Average Length (Line Blocks)	Percent of Messages Exceeding Average	Message Length Including 95% of Total (Line Blocks)
Flash	7	10	28	27
Immediate	7	18	25	50
Priority	8	42	22	300
Routine	9	47	16	400

The theoretical times to transit a 75-baud circuit for these representative message lengths are listed in Table 11.

From Table 11, it appears that the median length and average length messages transit the circuit easily relative to the standard, and that the 95 percent length is well matched to the standard if the only time involved in transmitting a message is the actual transit time. If there are queues or other sources of delay, a 75-baud circuit cannot meet the transmission standards with the message length distribution characterizing the present traffic. Either faster circuits must be used, or there must be an effort to reduce message length. Faster circuits, such as the 2400-baud voice line, are now coming into common use. They should resolve this contribution to the outlier problem.

Another cause of outliers is the retransmission of a message to any addressee who requests it. When a message is retransmitted from the originating TCC to the addressee, the message will still carry the original time of file. Hours may have elapsed between the original transmission and the retransmission, so the apparent transit time of the retransmission may be very long. Message retransmissions are readily controllable if they are caused by clerical errors in message preparation, but are only marginally controllable if they result from garbles (high bit error rates) because of hardware failures. One way to eliminate clerical errors is to introduce automatic equipment, such as an optical character reader to eliminate retyping of the message at the TCC, but this introduces other reliability problems. We turn next

Table 11

TIME TO TRANSIT 75-BAUD CIRCUIT
(Minutes)

Precedence	Time for Median Length	Time for Average Length	Time for 95% Length	Standard For T_4
Flash	1.0	1.4	3.8	3
Immediate	1.0	2.5	7	6
Priority	1.1	6.0	43	36
Routine	1.3	6.7	57	72

to the general question of the effect of hardware outages on speed of service, since an outage is equivalent to a delay.

EFFECTS OF HARDWARE OUTAGES ON SPEED OF SERVICE

The relationship between a hardware outage and the speed of service depends on the system configuration. Redundancy can significantly reduce the effect of individual outages, as is discussed below with reference to AUTODIN.

Figure 10 depicts single and multiple circuit paths. For a single path, as shown in the upper part of Fig. 10 (see also Fig. 6), an outage in the terminal equipment or the environmental support equipment in either the originating or destination TCC, an outage in a tributary circuit, or in either ASC, delays the transmission of all messages regardless of precedence level by a time at least equal to the duration

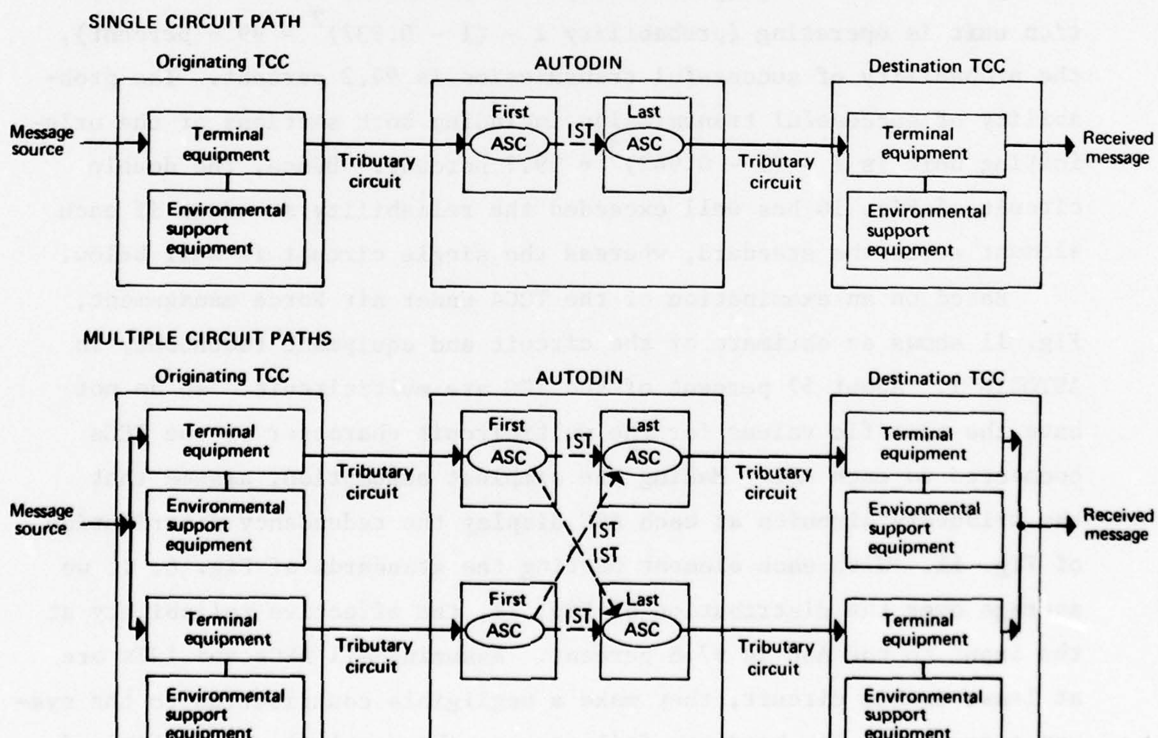


Fig. 10—Circuit configurations

of the outage. The growth in the message queue during the outage time can further increase system delivery time. Since all ASCs are multiply connected, outages in ISTs or in any ASCs intervening between the first and last will not generally add to the delay time of the highest precedence traffic.

For multiple circuit paths (lower part of Fig. 10) between the originating and destination TCCs, higher precedence traffic should not be significantly affected by outages in a single tributary circuit or a single piece of terminal or environmental support equipment. As calculated earlier for the single circuit path, if each element of the network just meets the efficiency standard, the efficiency of the entire net is 88.6 percent. If we regard the combination of each terminal and support, tributary, and ASC as a unit, the efficiency of that unit is 94.6 percent (product of the elements). If the IST and destination section are also regarded as a unit, its efficiency is 93.7 percent. Thus, if the upper section of the originating TCC in the multiple circuit path is operating (probability 94.6 percent), and either destination unit is operating (probability $1 - (1 - 0.937)^2 = 99.6$ percent), the probability of successful transmission is 94.2 percent. The probability of successful transmission including both sections of the originating unit is $1 - (1 - 0.942)^2 = 99.7$ percent. Hence, the double circuit of Fig. 10 has well exceeded the reliability standard if each element meets the standard, whereas the single circuit is well below.

Based on an examination of the TCCs under Air Force management, Fig. 11 shows an estimate of the circuit and equipment redundancy in AUTODIN I. About 57 percent of the TCC are multicircuit. We do not have the specific values for the multicircuit character of the TCCs connected to each ASC. Making the simplest assumption, assume that the tributary circuits at each ASC display the redundancy distribution of Fig. 11. With each element meeting the standards of Fig. 6, if we average over the distribution of Fig. 11, the effective reliability at the input to the ASC is 97.8 percent. Assuming all ASCs and ISTs are at least double circuit, they make a negligible contribution to the system outage time for hardware failures, so the complete reliability of the network would be $(0.978)^2 = 95.6$ percent. We thus see that under

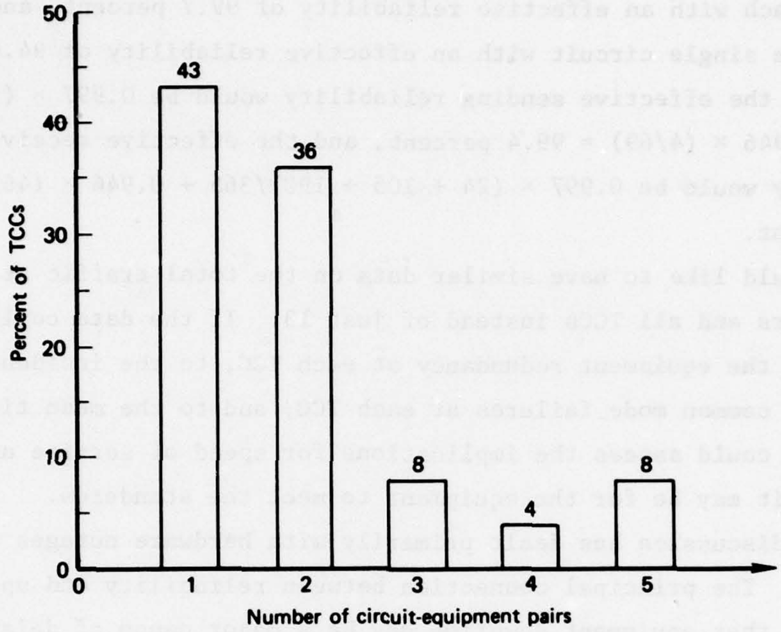


Fig. 11—Circuit-equipment redundancy

the simplest assumptions, the system reliability is considerably improved by the existing redundancy, but is far from what could be achieved by further increases in redundancy.

In actuality, the problem is not nearly so simple. The exact effect of redundancy on delays in the entire system depends not only on the net reliability of each TCC or ASC but also on the distribution of traffic. We surmise that the bulk of Flash traffic originates in major command headquarters, which are usually multicircuit, but a significant fraction of the recipients may be at low level, single circuit headquarters. This hypothesis is illustrated by the sample of Table 7. Only five of the 13 TCCs participating in the ACCWRS exercise originated Flash messages during this quarter year. Furthermore, using the largest number (n) for T_1, T_2, and T_3 of Table 7 to establish the number of actual messages, 54 out of 69, or 78 percent, originated in a single TCC. Nine of the 13 TCCs received Flash messages, but two of them received 295 of the 365 messages, or 81 percent. If the one principal transmitting and two principal receiving TCCs were double

circuit, each with an effective reliability of 99.7 percent, and all others were single circuit with an effective reliability of 94.6 percent, then the effective sending reliability would be 0.997 × (54 + 8 + 3)/69 + 0.946 × (4/69) = 99.4 percent, and the effective receiving reliability would be 0.997 × (24 + 105 + 190)/365 + 0.946 × (46/365) = 99.1 percent.

We would like to have similar data on the total traffic at all headquarters and all TCCs instead of just 13. If the data could be related to the equipment redundancy at each TCC, to the incidence of single and common mode failures at each TCC, and to the mean time to repair, we could assess the implications for speed of service and how difficult it may be for the equipment to meet the standards.

This discussion has dealt primarily with hardware outages and reliability. The principal connection between reliability and speed of service is that equipment downtime may be a major cause of delays. Thus, improvements in the equipment may eliminate many of the longer delays, particularly in T_4, where delays are almost entirely caused by equipment problems and by queueing. The queueing delays may be significantly reduced upon introduction of AUTODIN II, which employs 50 kilobits per second ISTs as compared to the 1.2 to 9.6 kilobits per second of AUTODIN I. However, as discussed earlier, T_4 makes the smallest contribution to the total system delay, T_1 through T_7, so improvements in equipment, which reduce that portion of the writer-to-reader delay, may have relatively little effect on the overall writer-to-reader delay.

Many users, especially those associated with the WWMCCS, are on-line (directly connected) to their AUTODIN switch. When AUTODIN II becomes operational, many additional users may be expected to come on-line, dramatically reducing their administrative handling delays (T_6 and T_7), because the hard copy appears at the addressee's location rather than at the TCC. The actual effect on delays in the complete AUTODIN network cannot be determined at present.

This completes those investigations of the AUTODIN I writer-to-reader delay problem described in this report. In a later report we shall give additional statistical analysis and will show for selected millimeter-wave satellite systems the actual effects of rain outages

on the complete delay distribution, thereby providing suitable context and information to evaluate the use of millimeter-wave satellite links for military communications. The next section gives the conclusions we can draw from the completed investigation.

VI. CONCLUSIONS AND FUTURE WORK

From the analysis of the earlier sections, we draw the following conclusions:

- The data described in this report show that the smallest contribution to the total message delay time is made by T_4, the AUTODIN I transit time. This is the only portion of the total delay which is affected by rain outages. We assert that the delays produced by rain outages should be compared to the delay in the complete path, rather than just to T_4, if a proper context for evaluation of earth-to-satellite millimeter-wave links in AUTODIN-type systems is to be achieved.
- The message population may be divided into two groups. About 60 to 70 percent are handled in 15 minutes for all seven time intervals; the remaining messages have much longer delays. Improvements in the speed of service for these outliers would have a much greater payoff for the overall system operation than would improvements for those messages which are already handled well.
- The administrative handling times contribute by far the most to long delays. Reduction of the time messages spend in TCC out boxes, T_6, or in local mail delivery, T_7, would have much more effect on decreasing the total delay time for each message than would reduction of the communications processing times. If electronic deliveries were employed, even if only for unclassified traffic, the delays would be substantially reduced.
- The distribution of values for any of the time intervals is severely skewed toward larger delays. The distribution is not well represented by a normal distribution. The mean and variance do not describe the distribution adequately.

- o The AUTODIN network serves the majority of users much better than is indicated by the mean. Thus, even though the mean values of delay for Flash messages are 2.92 hours for T_6 and 3.54 hours for T_7, 60 percent of the users experience delays of less than 15 minutes for these intervals. Characterizing delay by the mean makes the system look much worse than it actually is.
- o High precedence level messages do not meet the speed of service standards, according to the data developed in the ACCWRS and SNAPS studies. The large population of outliers makes the 95 percent point, which defines the standards, lie at very large delay times. Either the standard is unrealistically low and cannot be achieved, which could occur if long messages are sent over low data rate circuits, or the various phenomena which produce the outlier population must be found and corrected.
- o The reliability standards are met in a satisfactory manner by the use of redundancy in the network.

The following items are indicated for further study. Better distributions should be determined for the various delays than have been presented to date. We have obtained copies of the original records for the ACCWRS study, from which we are deriving the detailed delay distributions for all intervals but T_4. The records permit tracing individual messages through each ground section to obtain the distribution of the total handling times for outgoing messages ($T_1 + T_2 + T_3$) and incoming messages ($T_5 + T_6 + T_7$). Data we have secured from the DCA to supplement the SNAPS reports will enable us to determine the distribution of T_4, and we plan a set of calculations to provide the distribution of the complete writer-to-reader delay.

We wish to determine the effects of rain on this distribution. We have obtained data for various locations which provide distributions of rainfall rate with a one-minute resolution, from which we can calculate the distribution of the duration of rainfall exceeding a specified intensity. The intensity levels are selected to provide appropriate

margin for precipitation on earth-satellite links for ground stations in the indicated locations at chosen frequencies in the millimeter-wave band. Whenever the margin is exceeded, a rain outage occurs. These rain-outage duration distributions are combined with the existing distribution for T_4 to obtain the delay distribution when it is raining. A suitably weighted average then gives the effective long-term T_4 distribution. This is combined with the distribution for the other delay intervals to determine the complete writer-to-reader delay distribution for a communications system employing millimeter waves. The calculation described here will provide a basis for proper evaluation of millimeter-wave military communications satellite systems similar to AUTODIN. As mentioned in the Introduction, this report does not consider whether millimeter-wave links should be used in the AUTODIN system, but rather considers how to place in perspective the changes in system delay that might result if they were employed. Redundancy should reduce these consequences, as described in the text of this report.

Appendix A

THE ARMY COMMUNICATIONS COMMAND WRITER-TO-READER STUDY (ACCWRS)

This appendix provides information about the ACCWRS investigation which does not appear in the main body of this report. The study was undertaken by the Army Communications Command in November 1974, at the direction of the Department of the Army. The purpose was to establish a telecommunications management data base to document current telecommunications capability, and also to provide a baseline for measuring future improvements after automation through the U.S. Army Telecommunications Automation Program (ATCAP).[5] Although there is continual concern over message speed from writer to reader, emphasis is only on reducing "the length of time required to transmit a message from one military unit to another. Relatively little has been done to improve the time it takes to staff and insert the message into the communications system, and to deliver the message from the communications system to the action official."[5] ACCWRS gathered data to describe quantitatively the several time intervals associated with message transmission and to substantiate the relative importance of these intervals.

The data gathering phase of ACCWRS lasted from January 1975 through June 1976. Table A-1 indicates the number of time interval measurements accumulated during each quarter. Almost all (98.4 percent) of the measurements were taken between April 1975 and March 1976, so the study essentially covered one year. Thirteen Army TCCs throughout the world participated in the collection of the data. These 13 serve various size Army headquarters engaged in a variety of activities; they reflect the diversity of Army TCCs and their equipment. The volume of message traffic and the fact that some messages were sent to, or arrived from, TCCs other than the selected 13 precluded any attempt to trace each message from its inception to its delivery to an action officer. Instead, each of the 13 TCCs gathered data on all its outgoing message traffic and all its incoming message traffic.

The various time intervals are defined in Fig. 9 and the associated discussion, and will not be redefined here. We note that the time

Table A-1

NUMBER OF TIME INTERVAL RECORDS IN ACCWRS DATA BASE

Inclusive Dates	Number of Time Interval Measurements
January through March 1975	27,332
April through June 1975	522,204
July through September 1975	349,857
October through December 1975	428,932
January through March 1976	333,819
April through June 1976	---
Total	1,662,144

intervals T_1, T_2, and T_3 are associated with outgoing messages T_4 (not measured by ACCWRS) with messages in transit between TCCs, and T_5, T_6, and T_7 with incoming messages. The quantities actually recorded were not the intervals but their initiation and ending times. For outgoing messages, the relevant times (release by writer, final approval, arrival at originating TCC, and arrival at first ASC) were recorded by Army personnel on a special message preparation form. The times associated with incoming messages (message received at TCC, message available for delivery, message enters local distribution, and message reaches action officer) were entered on a slip stapled to the incoming message by destination TCC personnel. Copies of the originated messages and attached sample forms and copies of the incoming message slips were mailed periodically to ACC headquarters. From pairs of time values, ACC calculated the time intervals. If complete data (three time intervals per outgoing or incoming message) were available, only 554,048 messages would have been required to generate the 1,662,144 time interval measurements. Because of incomplete, inconsistent, or unreadable times, a somewhat larger number of messages were required to generate the data base, and there is a different total number of records for each time interval.

The data published by ACC cover a typical quarter year, 1 April to 30 June 1975, and include about 522,000 time interval samples.[4,5] A set of rejection criteria[5] eliminated about 0.7 percent of the measurements as excessively long and therefore probably erroneous (see

Table A-2). The data were sorted by precedence level, and the sample mean, standard deviation, 95 percent bounds, and other statistics are shown in Table A-3, which has been taken from Ref. 5. The upper and lower bounds were calculated as if the data were represented by a normal distribution (see Sec. IV), and most of the lower bounds are zero because of the large standard deviation. The means and standard deviations of Table A-3, shown in the first two numerical columns, have been calculated for the entire message set. The 95 percent tolerance intervals assert there is a 95 percent probability that 95 out of a sample of 100 messages will lie within the interval, while the 95 percent confidence interval indicates the interval which has a 95 percent probability of including the true mean processing time. The mean for each time interval was calculated from the message sample of each day, and then the standard deviation of these daily means was determined. Among the precedence levels, only Flash traffic displays wide fluctuation in the daily means.

Although the worst 0.7 percent of the data has been pruned, all the mean time intervals of Table A-3 seem exceedingly long. On a mean value basis, Table A-3 shows that T_3 and T_5 make the smallest contributions to the total message delay, and thus automating the TCCs while

Table A-2

EDITING CRITERIA

Time Interval	Rejection Criterion (Times Greater Than Indicated Value are Rejected) (Days)	Percent of Data Rejected
T_1	7	1.2
T_2	4	0.8
T_3	1	0.8
T_5	1	0.9
T_6	4	0.7
T_7	7	0.3
All intervals		0.7

Table A-3

ACCWRS STATISTICS FOR SIX TIME INTERVALS
AND FOUR PRECEDENCE LEVELS

Time Interval	Mean Value $\bar{T}$ (hr)	Standard Deviation σ (hr)	95% Tolerance Intervals for Individual Messages (hr)	Standard Deviation of Daily Means (hr)	95% Confidence Interval for Daily Means (hr)
T_1					
Routine	16.95	12.41	0.00-41.28	1.20	14.60-19.30
Priority	9.80	6.23	0.00-22.01	0.64	8.55-11.05
Immediate	4.35	7.85	0.00-19.74	0.87	2.64- 6.06
Flash	1.16	4.03	0.00- 9.07	0.66	0.00- 2.46
Average	15.31	8.98	0.00-32.92	0.50	14.33-16.29
T_2					
Routine	6.45	7.60	0.00-21.35	0.76	4.96- 7.94
Priority	3.93	3.30	0.00-10.40	0.34	3.26- 4.60
Immediate	2.36	2.76	0.00- 7.78	0.30	1.78- 2.94
Flash	1.50	3.18	0.00- 7.73	0.52	0.49- 2.51
Average	5.79	4.96	0.00-15.52	0.28	5.25- 6.34
T_3					
Routine	3.53	1.76	0.09- 6.97	0.18	3.19- 3.88
Priority	1.70	0.75	0.24- 3.16	0.08	1.55- 1.85
Immediate	0.46	0.31	0.00- 1.07	0.03	0.40- 0.53
Flash	0.25	0.51	0.00- 1.24	0.08	0.09- 0.42
Average	3.05	1.09	0.91- 5.19	0.06	2.93- 3.17
T_5					
Routine	1.50	1.34	0.00- 4.13	0.11	1.29- 1.71
Priority	1.23	0.86	0.00- 2.92	0.08	1.08- 1.38
Immediate	0.68	1.31	0.00- 3.25	0.13	0.42- 0.94
Flash	0.23	1.43	0.00- 3.03	0.17	0.00- 0.57
Average	1.38	1.23	0.00- 3.79	0.06	1.27- 1.49
T_6					
Routine	15.89	16.07	0.00-47.39	1.24	13.47-18.31
Priority	15.02	15.72	0.00-45.84	1.35	14.38-17.66
Immediate	10.53	10.77	0.00-31.63	1.11	8.36-12.70
Flash	2.92	6.11	0.00-14.89	0.78	1.40- 4.44
Average	15.43	14.01	0.00-42.90	0.65	14.15-16.71
T_7					
Routine	7.23	7.11	0.00-21.16	0.55	6.15- 8.31
Priority	5.82	3.93	0.00-13.53	0.34	5.16- 6.48
Immediate	6.21	4.82	0.00-15.66	0.49	5.25- 7.17
Flash	3.54	10.37	0.00-23.86	1.31	0.98- 6.10
Average	7.27	6.50	0.00-20.01	0.30	6.68- 7.86

leaving all other steps in the message path unchanged would produce little improvement in overall writer-to-reader speed of service, regardless of precedence level. However, a high precedence level does significantly improve the mean values of both the administrative and communications processing times.

The very large standard deviations, as compared to the means, indicate that the distributions have extensive tails and the means do not provide an adequate description. This subject is covered extensively in Sec. V of this report. In order to obtain a better understanding of the message statistics, Rand requested that ACC supply the complete distribution of the time intervals. In response, ACC prepared a cumulative distribution of writer-to-reader times for one TCC for the period covered by Ref. 5 (April through June 1975). The data were for narrative text only and were separated into the four precedence levels. Table A-4 shows the number of samples for each time interval in each precedence category. The very small number of outgoing Flash messages is immediately evident. The time interval distributions appear in Tables A-5 through A-8. These distributions have been discussed in Sec. V.

Table A-4

NARRATIVE MESSAGE SAMPLE SIZE FOR ONE TCC[a]

(Number of Messages)

Time Interval	Routine	Priority	Immediate	Flash
T_1	23,898	6,882	966	12
T_2	24,258	7,079	1,065	14
T_3	24,958	7,225	1,082	15
T_5	44,003	19,011	2,271	545
T_6	43,860	18,941	2,255	480
T_7	42,529	18,468	2,218	461

[a]For the period April to June 1975.

Table A-5

CUMULATIVE DISTRIBUTION FOR NARRATIVE FLASH MESSAGES FOR ONE TCC[a]

Percent of Messages	Time Interval (hr)[b] T_1	T_2	T_3	T_5	T_6	T_7
100	8.50	6.00	0.25	5.50	70.00	60.00
99	7.25	2.50		0.50	56.25	47.25
98					54.50	31.75
95				0.25	32.75	12.75
90	3.25	1.25			13.00	4.00
80	0.50	0.50			4.50	2.25
75					1.00	1.25
70		0.25			0.50	0.75
60					0.25	0.25
50	0.25					
40						
30						
25						
20						
10						

[a]For the period April to June 1975.

[b]ACC selected a 0.25 hr bin size.

Table A-6

CUMULATIVE DISTRIBUTION FOR NARRATIVE IMMEDIATE MESSAGES FOR ONE TCC[a]

Percent of Messages	Time Interval (hr)[b] T_1	T_2	T_3	T_5	T_6	T_7
100	115.75	48.25	3.25	10.25	95.75	146.76
99	24.00	24.75	1.00	1.00	70.25	64.50
98	16.75	23.75	0.75	0.75	64.50	46.75
95	3.50	7.00	0.50	0.50	57.25	19.00
90	2.25	4.00			46.00	10.50
80	1.25	2.50		0.25	22.25	5.25
75		2.00	0.25		14.75	4.75
70	1.00	1.50			12.50	4.00
60	0.75	1.00			9.00	3.25
50	0.50	0.75			4.25	2.75
40		0.50			2.00	2.00
30	0.25				1.00	1.25
25		0.25			0.75	1.00
20					0.50	0.75
10					0.25	0.25

[a]For the period April to June 1975.

[b]ACC selected a 0.25 hr bin size.

Table A-7

CUMULATIVE DISTRIBUTION FOR NARRATIVE PRIORITY MESSAGES FOR ONE TCC[a]

Percent of Messages	Time Interval (hr)[b]					
	T_1	T_2	T_3	T_5	T_6	T_7
100	166.00	95.75	21.50	21.75	95.75	167.25
99	76.25	44.75	3.25	3.25	78.75	78.50
98	50.25	27.00	2.50	2.50	68.25	69.25
95	24.50	22.00	1.75	1.75	61.25	28.00
90	16.00	8.00	1.25	1.25	40.75	20.50
80	3.50	3.75	1.00	1.00	16.50	6.50
75	2.75	3.00	0.75		14.50	5.00
70	2.25	2.50		0.75	12.75	4.00
60	1.25	1.75	0.50		9.50	3.25
50	0.75	1.25		0.50	6.25	2.25
40	0.50	1.00			3.50	1.75
30		0.75			2.25	1.25
25	0.25	0.50	0.25		1.75	1.00
20					1.50	0.75
10		0.25		0.25	0.75	0.25

[a]For the period April to June 1975.
[b]ACC selected a 0.25 hr bin size.

Table A-8

CUMULATIVE DISTRIBUTION FOR NARRATIVE ROUTINE MESSAGES FOR ONE TCC[a]

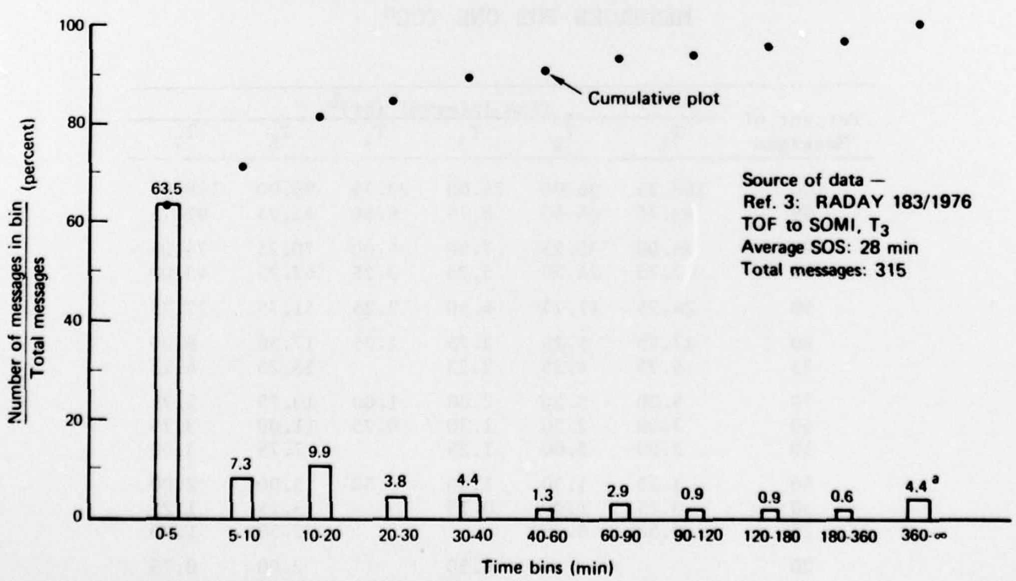
Percent of Messages	Time Interval (hr)[b]					
	T_1	T_2	T_3	T_5	T_6	T_7
100	168.25	96.00	24.00	23.75	96.00	168.00
99	95.75	66.50	8.75	6.50	82.25	92.75
98	76.00	35.25	7.50	5.00	70.75	74.25
95	47.75	24.50	5.75	3.25	62.25	43.00
90	24.75	17.75	4.50	2.25	51.75	23.25
80	17.75	5.25	2.75	1.25	17.50	8.00
75	6.75	4.25	2.25		15.25	6.25
70	5.00	3.50	2.00	1.00	13.75	5.25
60	3.00	2.50	1.50	0.75	11.00	3.75
50	2.00	2.00	1.25		7.75	3.00
40	1.25	1.50	1.00	0.50	5.00	2.00
30	0.75	1.00	0.75		3.25	1.25
25	0.50	0.75			2.50	1.00
20			0.50		2.00	0.75
10	0.25	0.50		0.25	1.00	0.50

[a]For the period April to June 1975.
[b]ACC selected a 0.25 hr bin size.

Appendix B

THE DCA SWITCH NETWORK ANALYSIS PROFILE SYSTEM (SNAPS) REPORTS

The Defense Communications Agency publishes data each month on the speed of service of AUTODIN I on the first Thursday of the month. This appendix summarizes the data taken on RADAY 183/1976 (1 July 1976) from the Switch Network Analysis Profile System (SNAPS) report,[3] which presents speed of service and message length distributions for each of the four precedence categories. Figures B-1 through B-4, taken from Ref. 3, show speed of service histograms for T_3 (TOF-SOMI), the originating TCC processing time, for Flash, Immediate, Priority, and Routine traffic, respectively. Figures B-5 through B-8 show similar plots for T_4, the AUTODIN I transit time. Finally, Figs. B-9 through B-12 show message length histograms for the four precedence categories. These figures have been used in Sec. V for detailed discussion of the speed of service for Flash messages and for comparison with standards at all precedence levels.



[a]The sum is only 99.9 percent due to round-off errors.

Fig. B-1—Flash speed of service histogram for T_3

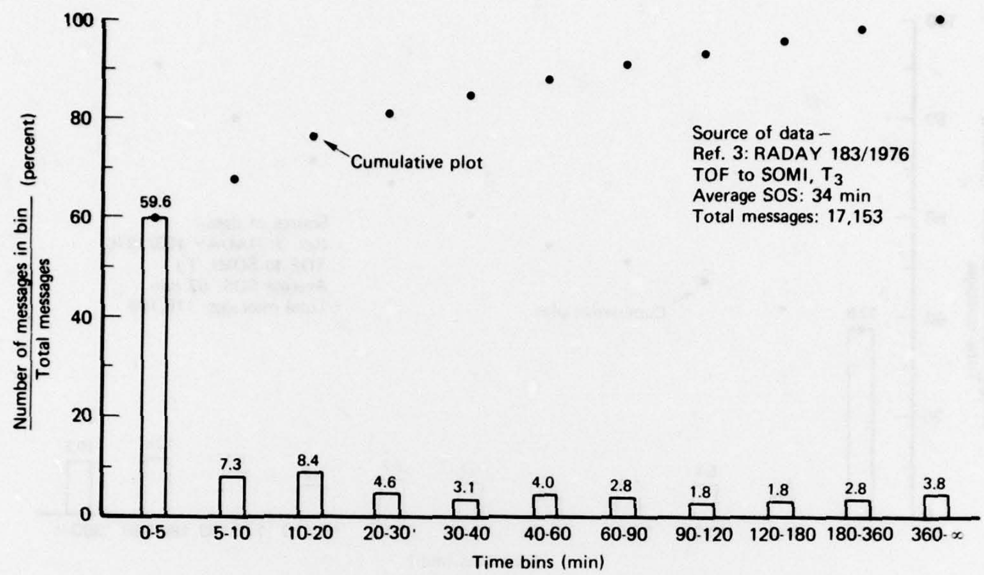


Fig. B-2—Immediate speed of service histogram for T_3

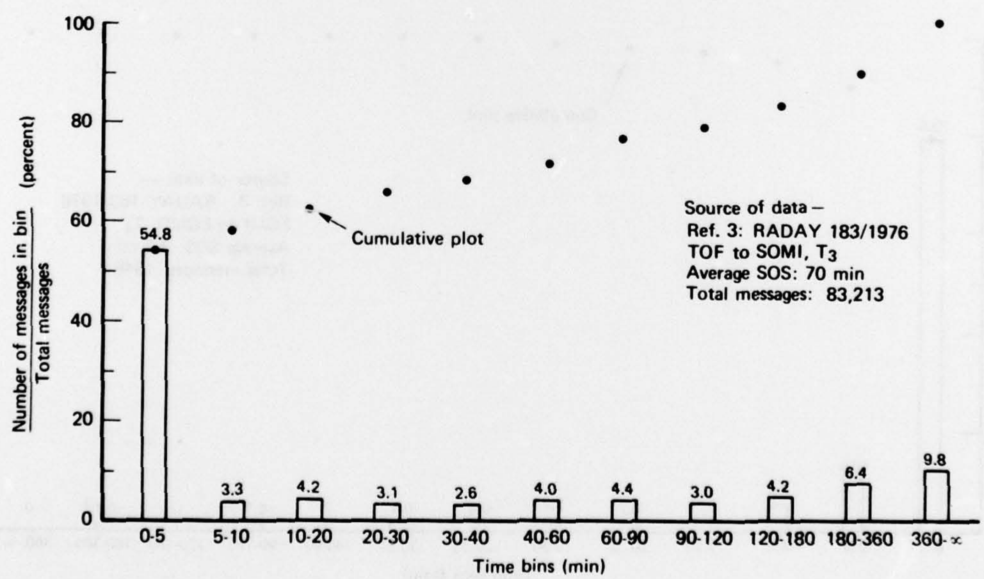


Fig. B-3—Priority speed of service histogram for T_3

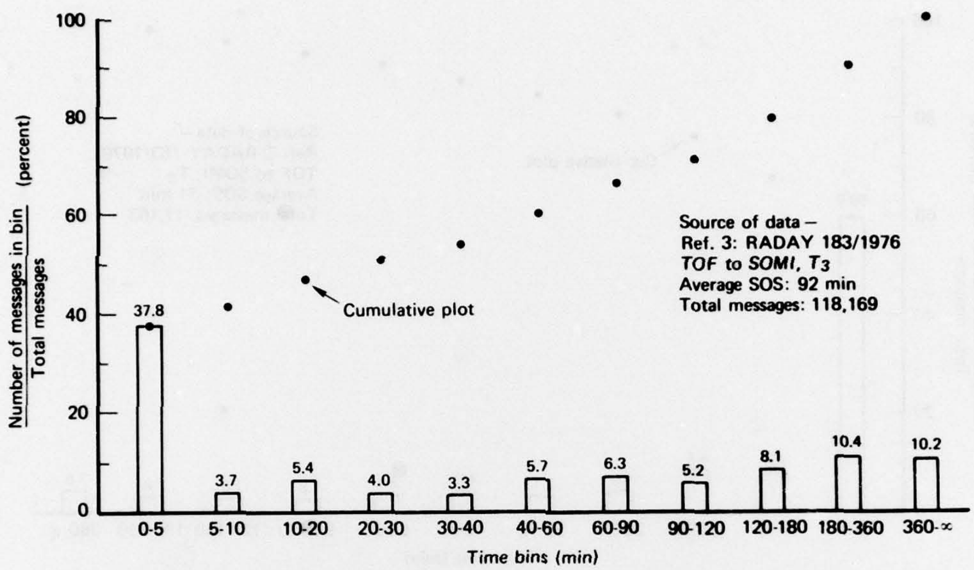
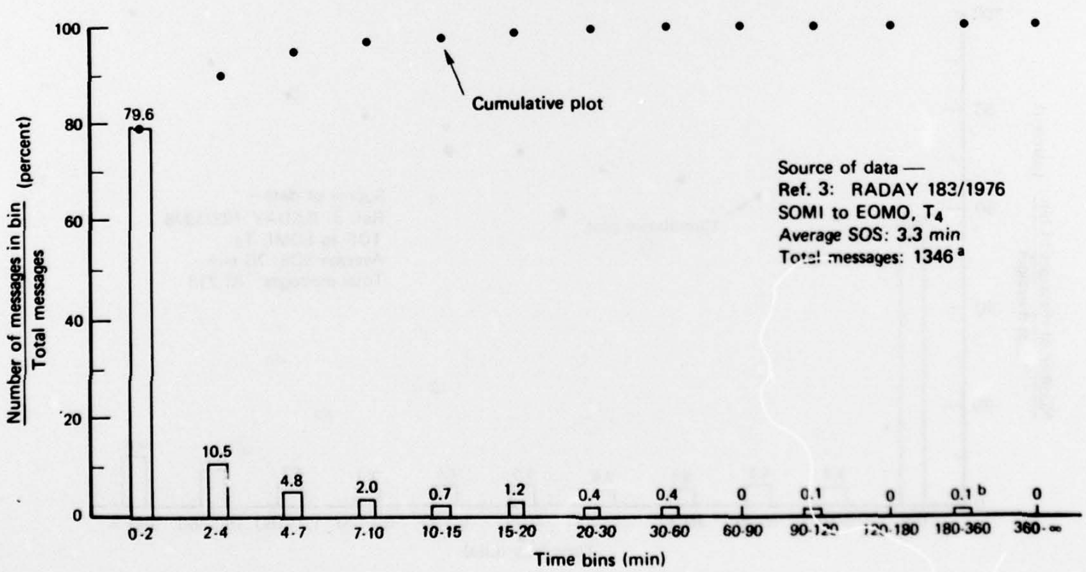


Fig. B-4—Routine speed of service histogram for T_3



[a] The 315 messages of Fig. 9 must have had an average of 4.27 addresses each, resulting in 1346 messages transiting AUTODIN.

[b] The sum is only 99.8 percent due to round-off errors

Fib. B-5—Flash speed of service histogram for T_4

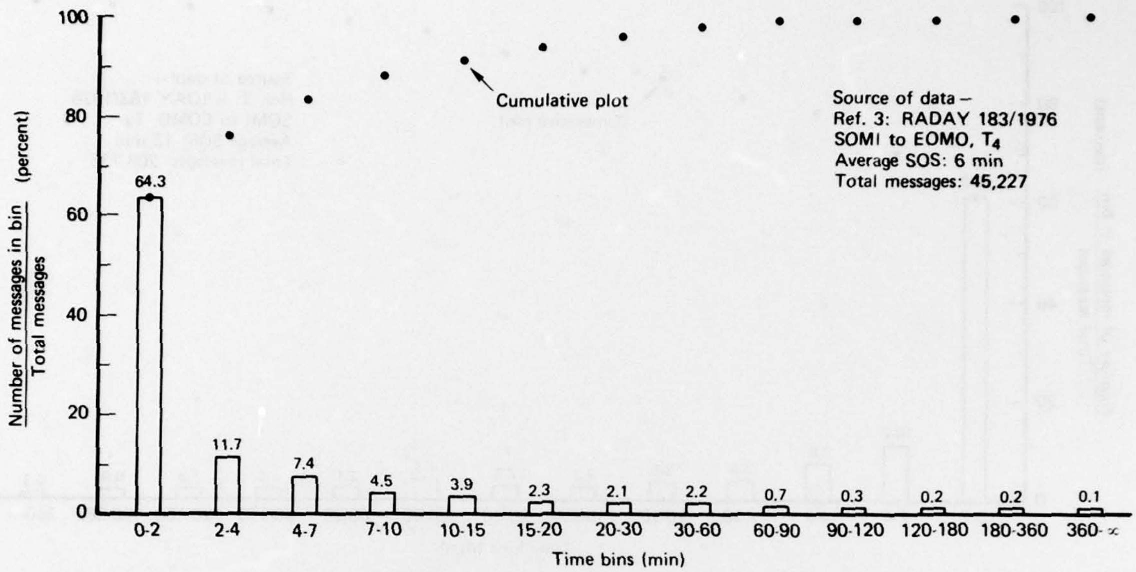


Fig. B-6—Immediate speed of service histogram for T_4

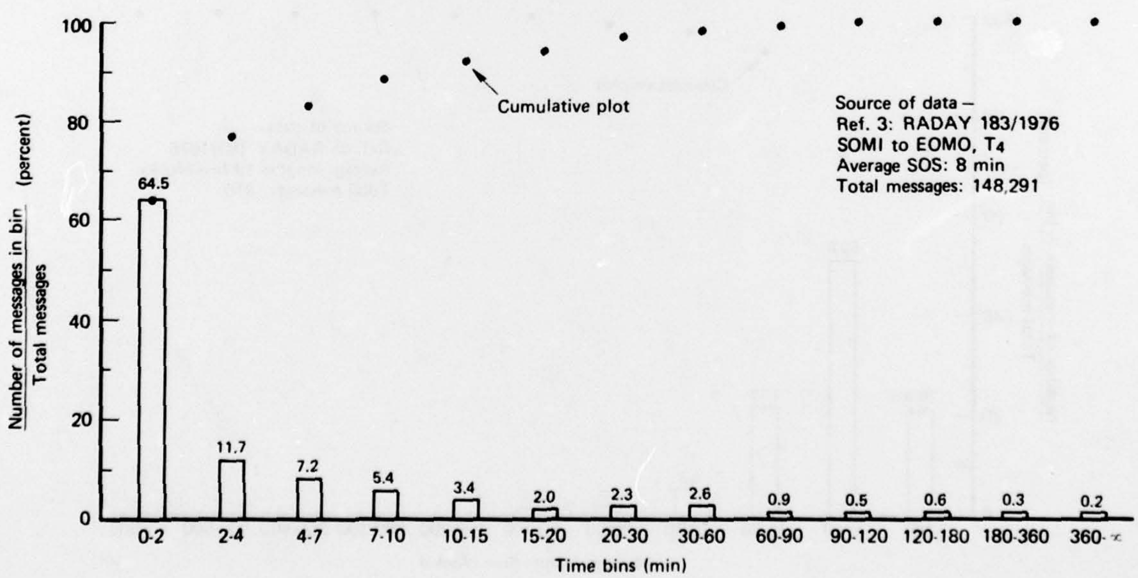


Fig. B-7—Priority speed of service histogram for T_4

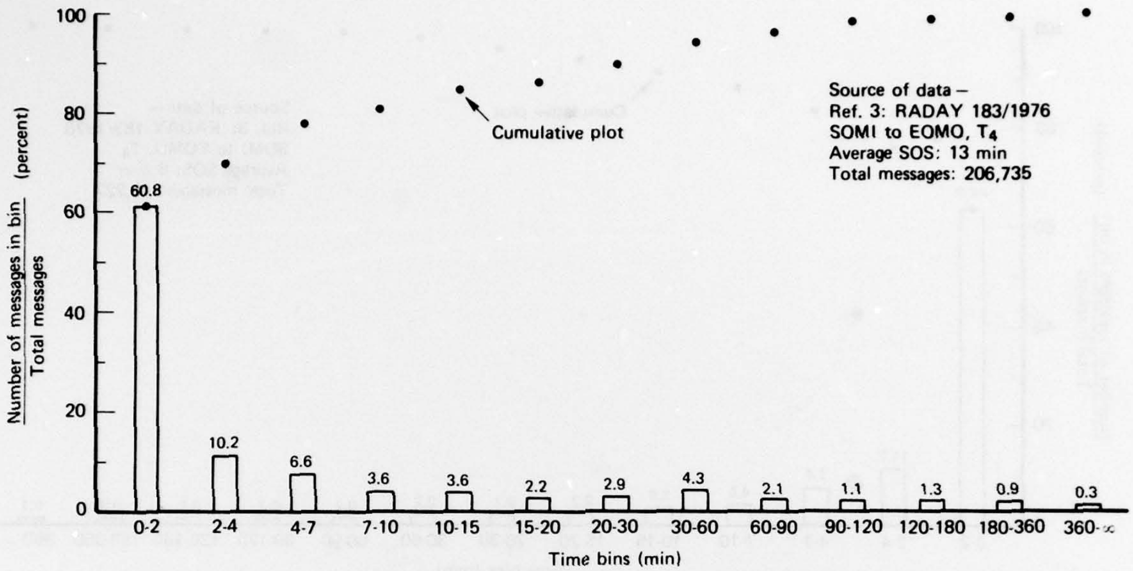


Fig. B-8—Routine speed of service histogram for T_4

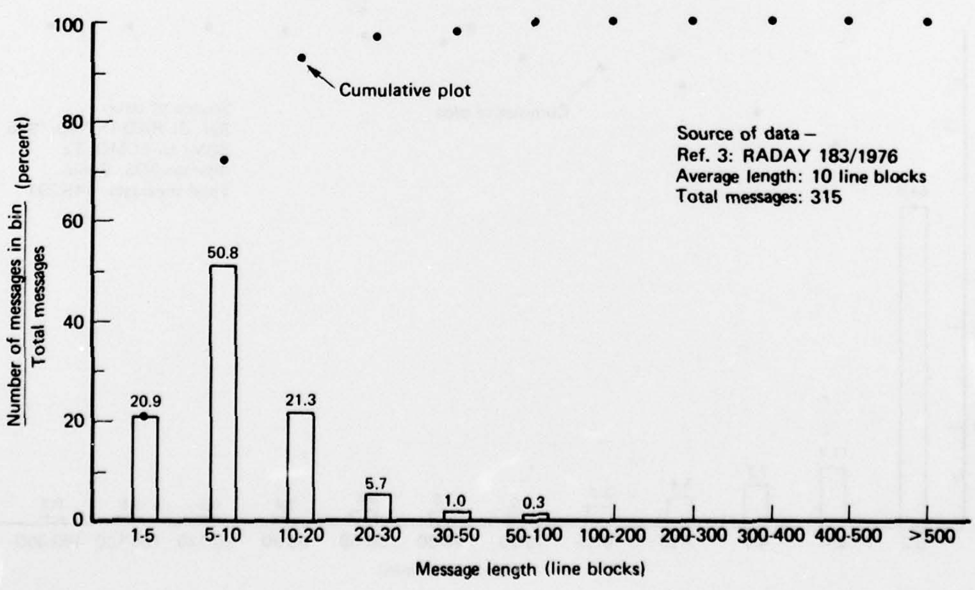


Fig. B-9—Flash message length histogram

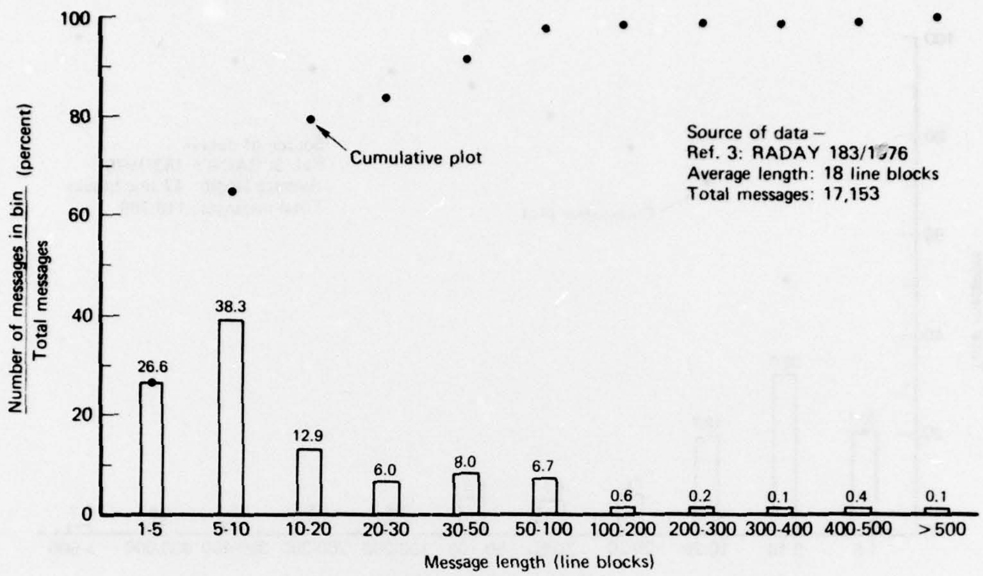


Fig. B-10—Immediate message length histogram

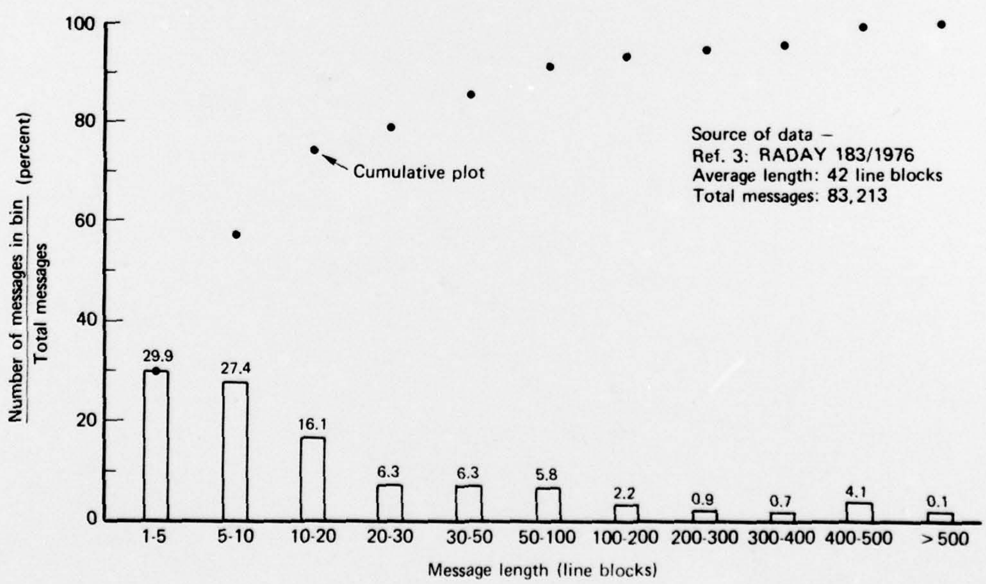


Fig. B-11—Priority message length histogram

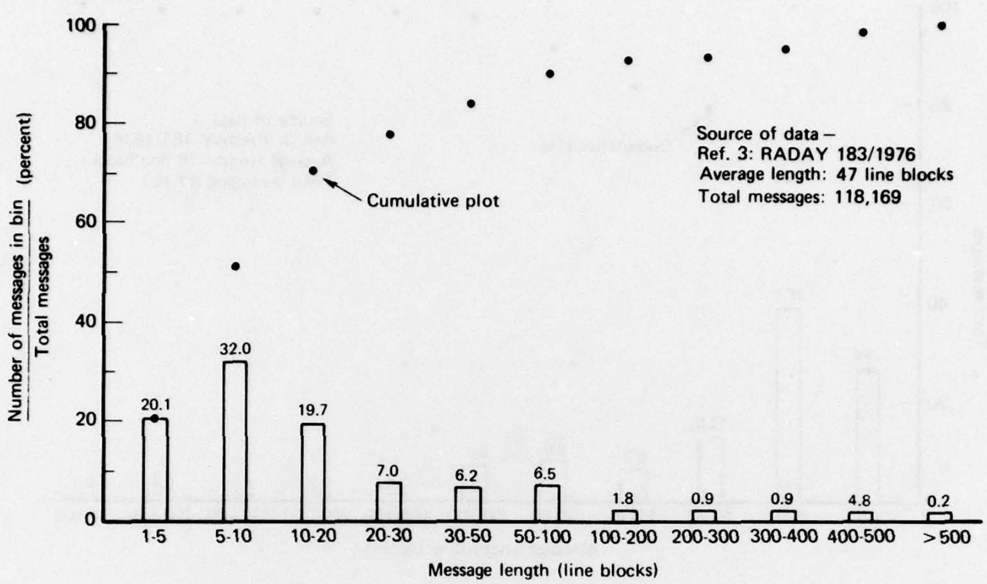


Fig. B-12—Routine message length histogram

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